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Aeroballistic Research Facility Data Analysis System (ARFDAS)

AD-A204 308

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AIR FORCE ARMAMENT LABORATORY
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NOTICE

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

Stephen C. Korn

STEPHEN C. KORN
Chief, Aeromechanics Division

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This report documents the computerized analysis programs used to examine free-flight, ballistic trajectory data (spatial position, angular orientation, and time) obtained at the United States Air Force Aeroballistic Research Facility (ARF). The Aeroballistic Research Facility Data Analysis System (ARFDAS) is a set of Fortran programs used to extract aerodynamic coefficients from experimental spark range data. This report, essentially a User's Manual, concentrates on how to utilize ARFDAS to conduct the desired analysis. The theory behind the derivation of the six degree of freedom equations of motion is fully explained by the references. The purpose of the report is to enable a person, who possesses a good knowledge of aerodynamics, to utilize the ARFDAS computer codes to analyze experimental data to final coefficient form.

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PREFACE

This program was conducted by the General Electric Company, Lakeside Avenue, Burlington, Vermont 05401-4985, under Contract F08635-87-C-0005 with the Air Force Armament Laboratory, Eglin Air Force Base, Florida 32542-5434. Lt. Roger Gates (AFATL/FXA) managed the program for the Armament Laboratory. The program was conducted during the period from October 1986 to September 1987.

This manual describes the Aeroballistic Research Facility Data Analysis System (ARFDAS) that is utilized by engineers at the Aeroballistic Research Facility to reduce experimental spark range data to aerodynamic coefficients. The intent herein is to demonstrate ARFDAS capabilities and utilization. The technical methodology is covered by the referenced documents. Extensive use is made of example input menus, and output presentation of results, to aid the user in understanding these complex computer codes.

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SECTION I

INTRODUCTION

The Aeroballistic Research Facility Data Analysis System (ARFDAS) is a set of Fortran programs used for the determination of aerodynamic coefficients from spark range experimental data. These programs are intended for use by engineers at the United States Air Force Aeroballistic Research Facility (ARF), an enclosed spark range used to examine the ballistic trajectories of experimental munitions in free flight (Reference 1). Two of the programs, Projectile Design Analysis System (PRODAS) and Modified Trajectory (MODTRAJ), are designed to estimate the aerodynamics of a projectile and create simulated test data. These programs are used to "design the experiment." The remaining programs use the test data (actual or simulated) to determine the aerodynamic coefficients from a best fit of the theoretical equations to the observed motion. The following menu is a list of program options currently available in ARFDAS.

```
Enter the number of the desired action

------------ Linear Theory ----------------

      1 - Input / Analysis
      2 - Output

---------------- 6 DOF ------------------

      3 - Setup
      4 - Analysis
      5 - Output

-------------- Auxiliary -----------------

      6 - Plot Experimental Data Points
      7 - Delete stored files
      8 - Run Time - Distance Bias
      9 - Run MODTRAJ
     10 - Run PRODAS
     11 - Breakup Tunnel XYZ files

     99 - Exit
```

In a typical analysis, PRODAS would be run first. In PRODAS, a finite element model of the projectile is created from which aerodynamic coefficient estimates of the model are found. These estimates will be used as the starting point for a least squares fit of the test data. An exterior ballistics analysis may be performed to determine the projectile motion. This data would be useful in locating cameras for a test firing. PRODAS may be used to create input data for the program MODTRAJ. In MODTRAJ a Six Degree of Freedom (6 DOF) motion analysis is performed. The motion data is correlated to each of the ARF's camera locations. Typical noise is then superimposed on the motion data. The resulting file may be run through the data reduction codes (linear and 6 DOF) to test for coefficient sensitivity.

After actual test data has been read from the film the Time-Distance Bias program is run. This program adjusts the projectile motion to account for measurement bias as found from a previously conducted range survey (calibration).

The biased experimental data may now be plotted. This visual examination makes it easier to show problems with the data such as points obviously out of position or long gaps between stations.

The first step in data reduction is the linear theory input/analysis. The linear theory analysis program creates input for the 6 DOF program. Plotted or tabulated output may be created from either the linear theory or 6 DOF programs. This report will further explain the theory of the analysis techniques and instructions for using the ARFDAS programs.

ARFDAS is implemented on one of the Eglin AFB VAX computers. The program utilizes the Tektronix graphics library Plot-10.

Throughout all the programs that comprise ARFDAS, common techniques for modifying data are used. The principal method is to display a menu of parameters for modification by the user. This is done by specifying the line number in the menu and the new value:

```
S87040613 40mm HEDP Tubular

   1 - Temperature            (deg C):    0.00
   2 - Pressure               (mbars):    0.00
   3 - Relative humidity  (40%=.40):      0.00
   4 - Projectile mass        (grams):    0.00
   5 - Projectile diameter (inches):      0.00

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue

   : 1,19.6
```

In the above example, the temperature will be changed from 0 to 19.6 degrees Celcius. The "LIST" option will redisplay the input menu showing any changes that have been made. The "DONE" option signals that modification is complete on this menu. Only the first character of the command is examined, therefore, only an L or D must be entered. The program will recognize either upper of lower case characters.

SECTION II

SIMULATED RANGE DATA (MODTRAJ)

MODTRAJ is a modified 6 DOF trajectory analysis program. Instead of outputting analysis results throughout the trajectory at specified time or distance increments, the data points are output when the horizontal travel matches the location of a camera station in the ARF. Random noise is then superimposed on the six output parameters (X, Y, Z, pitch, yaw, roll) before the analysis results are written to the data file for reading by Linear Theory Input. The probable errors of the noise were determined from the reading accuracy of the ARF range and are hardwired into the code. The only user input into MODTRAJ during program execution is the name of the data file written by PRODAS. The output data file from MODTRAJ will have the same name as the input file and is in the form of a Linear Theory input file.

The input for MODTRAJ is created by the trajectory segment of PRODAS (Section V). Selecting the MODTRAJ option in PRODAS will cause the contents of all trajectory input menus to be written into a data file for reading by MODTRAJ. PRODAS will not perform a trajectory analysis when running the MODTRAJ input option.

Once MODTRAJ has generated a trajectory, the resulting data points may be plotted. The following output menu shows the choices of plotted output:

```
             Theoretical Point Plots
     ___________________________________________

     vs time                          vs travel

       1 - Down Range Travel [X]        - 11
       2 - Horizontal Motion [Y]        - 12
       3 - Vertical Motion   [Z]        - 13
       4 - Pitch           [THETA]      - 14
       5 - Yaw               [PSI]      - 15
       6 - Roll              [PHI]      - 16

       7 - Pitch/Yaw       [THETA-PSI]
       8 - Pitch/Yaw Step Plot
       9 - Done

       : 4
```

Figure 1 shows a sample plot of pitch data for a 20mm projectile. Tabulated data may also be created by MODTRAJ upon exit. Table 1 shows a partial tabulated output created by the 20mm sample run.

A primary application of MODTRAJ is to generate data for simulated data reduction. This reduction can determine parameter sensitivity. Before performing a 6 DOF reduction on actual test data, the reduction of MODTRAJ data can determine which coefficients can be reduced with acceptable accuracy.

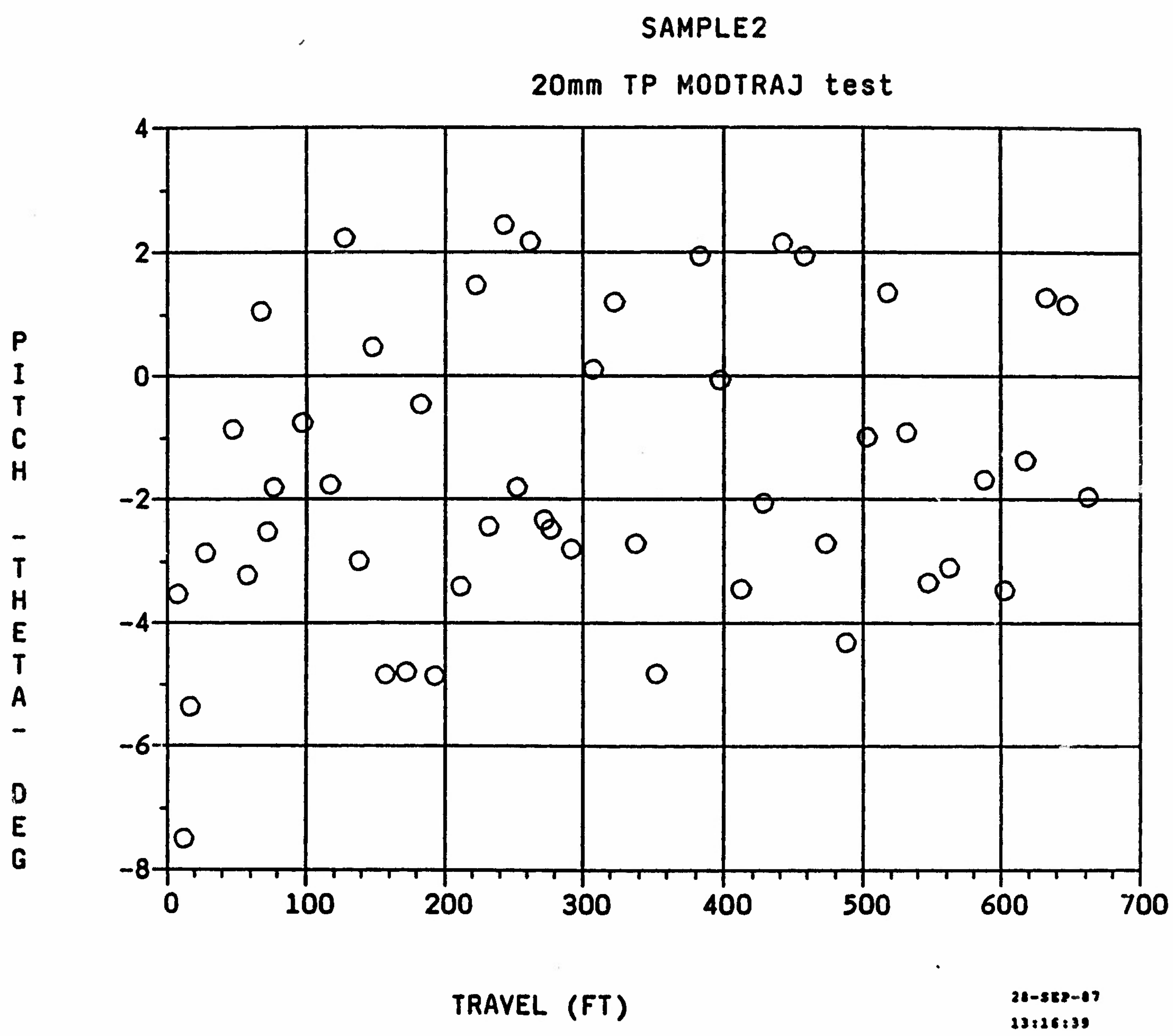


Figure 1. MODTRAJ Data Output

TABLE 1. MODTRAJ TABULAR OUTPUT

MODTRAJ Documentation test case

6 Degree of Freedom Trajectory Program

Input Data

Projectile Diameter (in)	Axial Inertia (lbm-in**2)	Y Transverse Inertia (lbm-in**2)	Z Transverse Inertia (lbm-in**2)	Product of Inertia (lbm-in**2)	Projectile Weight (lbm)	Number of Fins	Table Size
0.531	0.00758	0.05857	0.05857	0.00000	0.23048	0	17

Elevation Angle (deg)	Azimuth Angle (deg)	Angle of Attack (deg)	Angle of Sideslip (deg)	Pitch Rate (rad/sec)	Yaw Rate (rad/sec)	Roll Rate (rad/sec)	Muzzle Velocity (ft/sec)	Integration Time Step (sec)
1.000	0.000	0.000	0.000	40.000	40.000	13947.	4350.	0.00020

Initial Conditions

Altitude (ft)	Horizontal Range (ft)	Cross Range (ft)	Time (sec)
0.000	600.000	0.000	0.000

Aerodynamic Coefficient Tables
(For Fixed Plane EOM)
Mach Numbers

COEFF	(CNA=CZA)								
1		0.01	0.60	0.90	0.95	1.00	1.05	1.10	1.20	1.35
		1.50	1.75	2.00	2.50	3.00	4.00	5.00		
2 CX0		0.19800	0.19800	0.20040	0.22000	0.25900	0.37100	0.42700	0.41800	0.39200
		0.34600	0.31300	0.28200	0.23000	0.19000	0.15200	0.13000		
3 CXa2	(ABAR)	2.43650	2.43650	2.87710	3.30810	3.74890	4.24410	4.70300	5.20910	5.74050
		4.57610	3.98260	3.39740	2.90580	2.46530	2.04520	1.62510		

Temperature (Deg F): 59.02
Pressure (psi): 14.692
Density (slug/ft**3): 0.00237692

TABLE 1. MODTRAJ TABULAR OUTPUT (CONCLUDED)

Time (sec)	Travel X (ft)	Travel X (m)	Travel Y (ft)	Travel Z (ft)	Velocity X (ft/sec)	Velocity Y (ft/sec)	Velocity Z (ft/sec)	Projectile Velocity (ft/sec)	Slant Range (ft)
0.000000	600.00	182.88	0.000	0.000	4349.	0.00	75.92	4350.0	0.000
0.000199	600.87	183.14	0.000	0.015	4349.	0.01	75.90	4349.8	0.868
0.000399	601.73	183.41	0.000	0.030	4349.	0.05	75.87	4349.7	1.735
0.000598	602.60	183.67	0.000	0.045	4349.	0.11	75.84	4349.5	2.603
0.000798	603.47	183.94	0.000	0.061	4349.	0.20	75.81	4349.4	3.470
0.000997	604.34	184.20	0.000	0.076	4349.	0.32	75.80	4349.2	4.338

Time (sec)	X (ft)	X (m)	Roll Rate (rad/sec)	Mach Number	Pitch (missile) (deg)	Yaw (missile) (deg)	Pitch (deg)	Yaw (deg)	Angle of Attack (deg)
0.00000	600.00	182.88	0.	0.000	0.000	0.000	0.000	0.000	0.000
0.00020	600.87	183.14	13946.	3.896	0.366	0.529	-0.156	-0.624	0.643
0.00040	601.73	183.41	13946.	3.896	0.527	1.161	-0.370	1.220	1.275
0.00060	602.60	183.67	13946.	3.896	0.459	1.827	1.396	-1.266	1.884
0.00080	603.47	183.94	13945.	3.895	0.165	2.457	-2.415	0.483	2.462

Time (sec)	X (ft)	X (m)	Roll Rate (rad/sec)	Pitch Rate (rad/sec)	Yaw Rate (rad/sec)	Pitch (deg)	Yaw (deg)	Gamma (deg)	Delta (deg)	Roll (deg)
0.00000	600.00	182.88	13947.	40.00	40.01	-1.000	0.000	1.00	0.00	0.
0.00020	600.87	183.14	13947.	23.53	51.77	-0.634	0.529	1.00	0.00	159.
0.00040	601.73	183.41	13946.	4.26	57.90	-0.473	1.162	1.00	0.00	319.
0.00060	602.60	183.67	13946.	-15.98	57.84	-0.540	1.829	1.00	0.00	478.
0.00080	603.47	183.94	13946.	-35.28	51.59	-0.835	2.460	1.00	0.00	637.

AERODAS input Tunnel XYZ data (with random noise)

Time (sec)	Y (in)	Z (in)	X (ft)	Pitch	Yaw	Roll (deg)
0.0001994	-0.0090	0.1866	600.8658	0.00801	0.01061	158.3
0.0003989	0.0142	0.3367	601.7347	0.02018	0.00456	317.5
0.0005983	-0.0023	0.5505	602.6030	0.03048	0.00913	118.0
0.0007978	-0.0029	0.7260	603.4679	0.04076	0.01408	276.1
0.0009972	0.0095	0.9083	604.3397	0.05257	0.02470	76.6
0.0091746	0.0148	8.5087	639.8701	-0.01910	-0.02424	130.9

SECTION III

TIME-DISTANCE BIAS (TDBIAS)

The Time-Distance Bias (TDBIAS) program serves two objectives: (1) a preliminary fit to the experimental time-distance data to screen for erroneous timing data, and (2) the option of superimposing statistical bias data based on the range calibration. The program will flag the user to potentially suspect data. Corrections to the data may be entered from within the program. Generally the statistical biasing data will be superimposed to improve data quality. For biased data the program will prefix the shot number with the letter B.

The data resulting from the film readings is stored in a file containing multiple shots. The first step in program execution will be to specify the name of this file. The shots from this file will be selected individually for biasing. A LIST option is available to display the name of all shots within the composite file.

The following illustrates the shot selection procedure:

```
Enter the name of the file containing the raw data: TUNDAT
Key in 10 digit projectile title (or LIST): LIST
   Basic range data projectile titles (TUNNELXYZ)

   S87040613 40 MM HEDP  TUBULAR REREAD
   S87040209 40 MM HEDP  TUBULAR REREAD
   S87080617 20 MM BOOMED/CASED
   S87080618 20 MM BOOMED/CASED
   S87032490 40 MM HEDP  TUBULAR
   S87032797 40 MM HEDP  TUBULAR

Key in 10 digit projectile title (or LIST): S87040613
```

For the shot selected, the following physical and atmospheric properties must be entered:

```
S87040613 40mm HEDP Tubular

  1 - Temperature          (deg C):    0.00
  2 - Pressure             (mbars):    0.00
  3 - Relative humidity  (40%=.40):    0.00
  4 - Projectile mass      (grams):    0.00
  5 - Projectile diameter (inches):    0.00

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue

  : 1,19.6
```

A curvilinear regression fit is performed on the data using the IMSL mathematics library. This curve fit finds a 3rd order time solution. This equation along with the input echo, experimental times, and curve fit times will be printed out:

```
BS87040716   40 MM HEDP   TUBULAR

TIME =  -0.3530054E-10 * X**3 +   0.1876861E-06 * X**2 +
         0.9585853E-03 * X    +   0.5469398E+00

Temperature (Deg C):  19.60
            (Deg F):  67.28
            (Deg R): 526.92

Pressure      (mbar): 1017.000
          (lbf/ft**2): 2124.513
Humidity            :    0.520

Mass         (grams):   244.00
Mass         (slugs): 0.016719

Diameter        (in):   1.575
Area         (ft**2): 0.01353

PV      (lbf/ft-sec):   24.74380
RHO    (slug/ft**3): 0.00233652

DBSQ                :    0.00
TA             (deg):    0.00
```

BS87040716   40 MM HEDP   TUBULAR

Distance (ft)	Input Time (sec)	Fit Time (sec)	Delta (sec)	Velocity (ft/sec)	CD	
11.9377003	0.5584267	0.5584099	-0.1680851E-04	1038.366	0.409506	
17.1982994	0.5634965	0.5634812	-0.1525879E-04	1036.259	0.407454	
27.1723995	0.5731447	0.5731248	-0.1990795E-04	1032.304	0.403592	
47.2350998	0.5925861	0.5926338	0.4768372E-04	1024.506	0.395938	***
57.1082993	0.6022863	0.6022886	0.2324581E-05	1020.745	0.392227	

```
Standard Deviation :          0.0000159308
XR Average         :          0.0000000191
```

Note in the above partial printout that the point at 47.235 feet is flagged with "***." Any point where the error in time exceeds 1.5 standard deviations will be flagged. This flag is only to call attention to the point for possible action by the engineer; no program action is taken.

Once the curve fit has been displayed, the user has the following options:

```
Enter number of the desired option

        1 - Edit current data
        2 - Plot fit results
        3 - Refit the current data
        4 - Store the edited/biased data
        5 - Select a new shot
        6 - Print tabulated file on exit or new shot
        7 - Exit

: 1
```

Editing may be done on the time or roll at each station. Entering a negative time will remove the station from the analysis. A value of -99 for roll will result in the roll data being ignored by the Linear Theory and 6 DOF analyses. The following is a partial listing resulting from entering the edit option:

```
Tunnel XYZ data for editing

Enter negative time to remove a station

 Station                                      Station
Distance        Time          Roll        Distance         Time          Roll
 (feet)         (sec)         (deg)         (feet)         (sec)         (deg)

 11.9377 ( 1) 0.5584267 (14) -99.   242.0256 (27) 0.7894410 (39) -99.
 17.1983 ( 2) 0.5634965 (15) -99.   252.0643 (28) 0.7999383 (40) -99.
 27.1724 ( 3) 0.5731447 (16) -99.   271.9348 (29) 0.8207810 (41) -99.
 47.2351 ( 4) 0.5925861 (17) -99.   276.9530 (30) 0.8260718 (42) -99.
 57.1083 ( 5) 0.6022863 (18) -99.   291.9944 (31) 0.8419708 (43) -99.
 67.0824 ( 6) 0.6120735 (19) -99.   306.9884 (32) 0.8578804 (44) -99.
 72.1105 ( 7) 0.6170182 (20) -99.   322.0588 (33) 0.8739316 (45) -99.
 76.9907 ( 8) 0.6218238 (21) -99.   352.1425 (34) 0.9062108 (46) -99.
151.9478 ( 9) 0.6967998 (22) -99.   382.1923 (35) 0.9387400 (47) -99.
181.9187 (10) 0.7273291 (23) -99.   397.1584 (36) 0.9550332 (48) -99.
186.9524 (11) 0.7324781 (24) -99.   412.1839 (37) 0.9714601 (49) -99.
212.0999 (12) 0.7583820 (25) -99.   442.1961 (38) 1.0044963 (50) -99.
222.1359 (13) 0.7687663 (26) -99.

    Key in item number "," new value
    Key in "LIST" to relist "DONE" to continue

    : 13,-1
```

In the above example, the data associated with number 13 (222.1359 feet) was eliminated.

The following plots may be created:

Enter the number for the desired operation

1 - Time - fit plot
2 - Velocity versus Distance
3 - CD versus Distance
4 - Done

: 1

The time plot includes both time versus distance and error at each station. The bar graph makes it easy to spot obvious errors such as erroneous input times. See Figure 2 for a sample TDBIAS time fit plot. The other plots are self-explanatory.

When the data is stored it will be written in an individual file by shot number for reading by the Linear Theory input program.

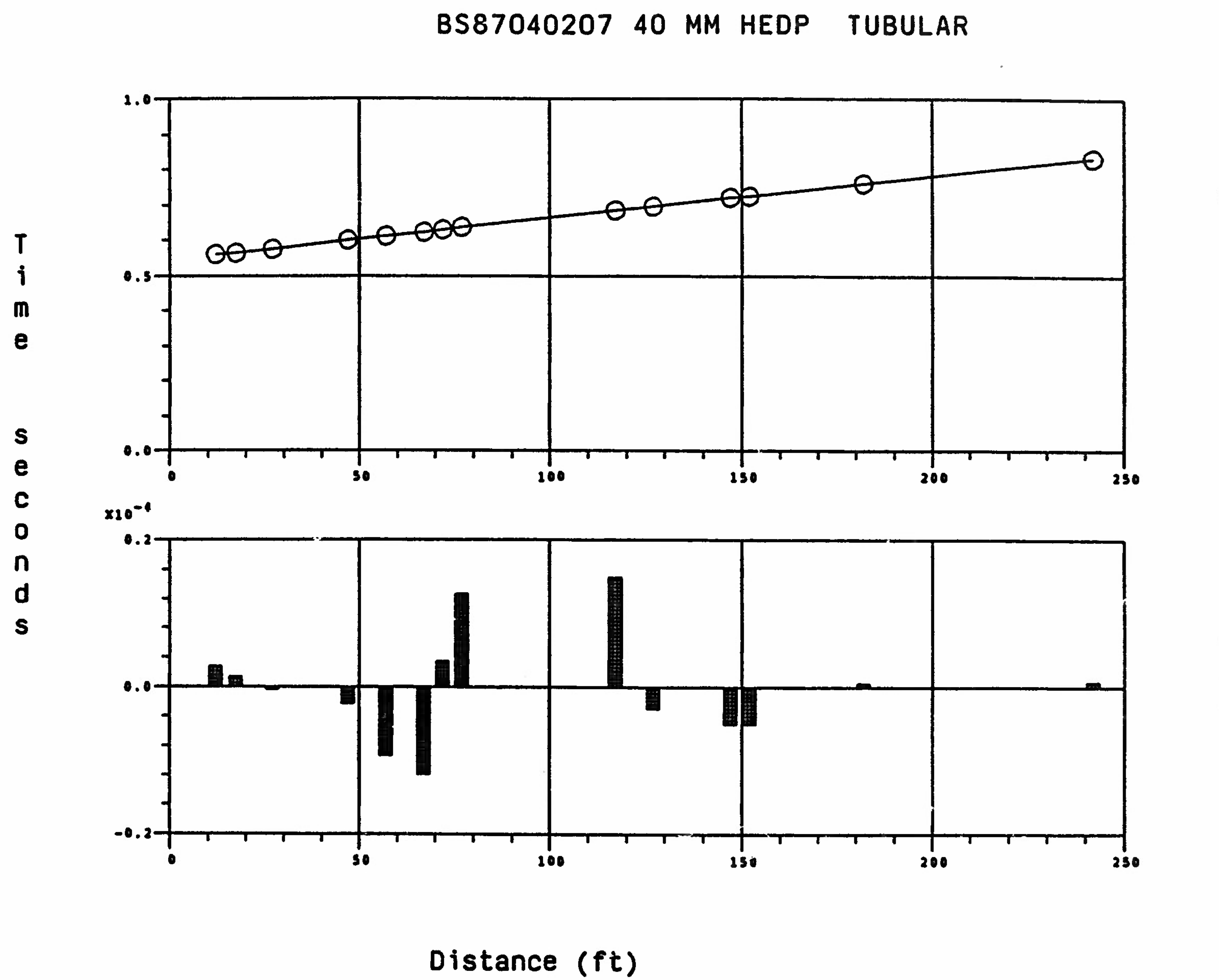


Figure 2. TDBIAS Results

SECTION IV

PLOTTING EXPERIMENTAL POINTS

This program allows the user to read in the experimental data points, as they come from the film readings or TDBIAS program, and create scatter plots. The points are plotted without any reduction or analysis being performed. This allows the user to examine the data prior to attempting to analyze it. One reason the engineer may wish to do this might be to determine the degree of angular motion present during the flight. Large angles could alert the engineer that non-linear aerodynamics might be present, or very small angles could indicate that certain angle dependent coefficients might be difficult to determine. The following menu will be displayed for plot choice:

```
        Linear Theory Experimental Point Plots
       ----------------------------------------

        1 - Horizontal Drift   [Y] vs Down-Range Travel [X]
        2 - Vertical Drop      [Z] vs Down-Range Travel [X]
        3 - Roll             [PHI] vs Down-Range Travel [X]
        4 - Pitch          [THETA] vs Down-Range Travel [X]
        5 - Yaw              [PSI] vs Down-Range Travel [X]

       99 - Done
    :
```

Figure 3 shows the experimental yaw data for a 40mm projectile.

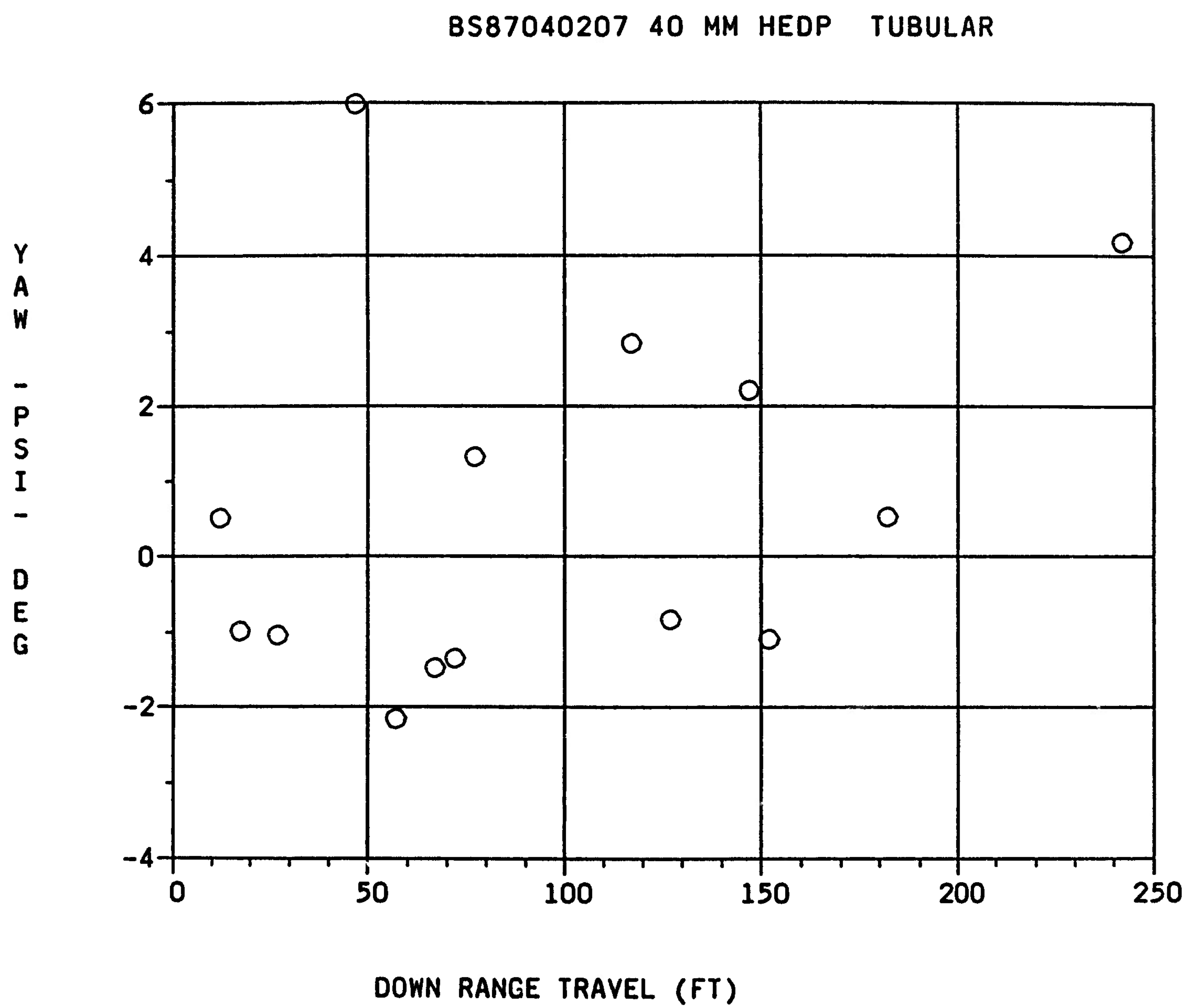


Figure 3. Experimental Points Only Plot

SECTION V

PROJECTILE DESIGN ANALYSIS SYSTEM (PRODAS)

1. GENERAL

PRODAS, as installed at ARF is a Fortran program used to aid the engineer in performing stability and exterior ballistic analyses. The program uses a common data structure to pass information among independent modules to facilitate rapid projectile design and analysis. The program uses interactive menus in combination with Tektronix Plot-10 graphics to provide a user friendly environment. Input/output may be performed in either english or metric units. The program has been used for projectiles from 5.56mm to 8 inches in diameter.

The first step will be to specify the terminal being used:

1 - Large Screen
2 - Small Screen
3 - Large Screen Color (Tek 4105)
4 - Small Screen Shaded Color (Tek 4105)

Choosing the large or small screen will determine the number of lines printed on a page and the number of columns in a line. The small screen is limited to 26 lines of 80 columns. The large screen has 55 lines of 132 columns to a page. In the small screen mode, the text is output as Tektronix character size 2. In the large screen mode the text size will be smaller. The large screen mode will take fewer pages than the small screen mode but the small screen mode will be more readable.

PRODAS also supports the Tektronix 4100 series color terminals. Options Three and Four will use these terminals to make color line plots, and use the shaded areas capability to make color shaded drawings of the projectile. For the color shaded drawing to appear correct, the model must be constructed in a specific manner. The rules for model construction are explained in the Edit New (EN) module.

After the terminal type has been specified, the main menu for the program will be displayed. The appearance of this menu is different for the large and small screen modes.

Select code of desired analysis from the following menu

EN Enter new data
EF Read existing data file
EE Edit existing data

M Physical Properties
S Stability Analysis
T 2/6 DOF Trajectory

C Catalog Data
DF Delete Existing File
B Exit PRODAS

Enter code for desired operation:

Each module of PRODAS is accessed by entering a one or two character mnemonic. As each module is completed, the program will return to this menu.

2. PRODAS PROGRAM SEGMENTS

The following paragraphs detail each of the program segments.

When running an analysis, data is passed among the modules. This requires that the analysis be run in a specific order. Once data has been cataloged it will not be necessary to run that module again unless the projectile has been changed.

The Physical Properties (M) module must be run before any other analysis module.

a. EN - Enter New

The first step in running an analysis on PRODAS will be the construction of the projectile model. The projectile model is a finite element representation of the projectile to be analyzed. The model is composed of positive and negative density frustums, each called an element. A model may contain up to 150 elements. Most projectiles can be adequately modeled with 50-75 elements. The elements that make up the model are divided into nine categories, each defined by the physical function of the element. These categories are called component codes. The component codes are:

-2 Boom
-1 Sabot
0 Projectile Body
1 Penetrator
2 Filler
3 Rotating Band
4 Ogive
5 Boattail
6 Fin

When accepting a new model, the program will prompt the user for a file title, description, and input/output units. The program will then accept element data until a <cr> is entered (Table 2). Each element requires eight parameters:

left diameter
right diameter
length
reference length
density
component code
radius
color code

All elements, except fins, are assumed to be radially symmetric. The model must be constructed such that the projectile points to the right and all geometry lies within positive space. The reference length is the distance from the origin to the left edge of an element. It is not necessary for the base of the projectile to be at the zero reference length. When entering data, it is not necessary to enter trailing zeros.

The color code is used to create color shaded models on Tektronix 4100 series terminals. The codes signal the program as to which patterns to use in drawing the element. Color codes may run from 1 to 16. If a code is not defined by the user, one will be assigned by the program when the model is read in Enter File Module (EF) based on the component code. For a model to look correct when drawn in color, it is necessary to enter elements in a specific order. Elements will be displayed in numerical order. Negative density elements are drawn with the background color (index 0). The negative elements must be displayed before elements are displayed that fill in this volume. The easiest way to remember the proper sequence is to create the models from the outside in. Create the rotating band and sabot first. Create the fin, then the body, penetrator, and ogive. Any high explosive filler will probably be last. Within the Edit Existing (EE) module is the ability to renumber elements to correct errors.

If a fin element, component code 6, was entered, the program will request the fin details. These are seen at the bottom of Table 2. Under normal operation these will be on a different screen.

After the fin has been defined, the program will proceed to the Edit Existing (EE) module to accept corrections to the model (Figure 4).

TABLE 2. ELEMENT DATA

```
Enter 9 character file title
: MAFMODEL
Enter descriptive text
: EN DEMONSTRATION

Enter type of units for file
    1 - English     2 - Metric
: 1

Enter element parameters seperated by commas
left dia, right dia, length, ref. length, density, code, radius, color code

-2 Boom   -1 Sabot     0 Body   1 Penetrator   2 Filler   3 Band
 4 Ogive   5 Boattail   6 Fin    7 Tracer

Letters may be used for densities:
S Steel,  A Aluminum,  T Tungsten,  P Plastic,  D DU,  H  HE,

  1: 1,1,2,0,.1,0,0,0
  2: 1,0,2,2,.1,4,0,0
  3: 2,2,1,0,.1,6,0,0
  4:



Enter fin group information

Fin Types

1 - Rectangular          2 - Delta
3 - Clipped Delta        4 - Swept Rectangular

Number of Fin Groups(<4)          : 1

Enter element numbers in fin group 1 separated by commas
: 3


Fin Type                          : 1
Projectile Diameter at Fin   (in): 1.0
Fin Trailing Edge Thickness  (in): .05
Fin Leading Edge Thickness   (in): .05
Number of Fins in Group           : 4
```

Edit Menu

1 File Title
2 Elements
3 Fin Information
4 Scale Model
5 Tabulate Model Data
6 Zoom
7 Change Units
8 Change Ref. Length
9 Change Element #
10 Change Ref. Dia.
11 Change Density
12 Mass Properties
99 Return to Main Menu
:

Filename: MAFMODEL

EN DEMONSTRATION

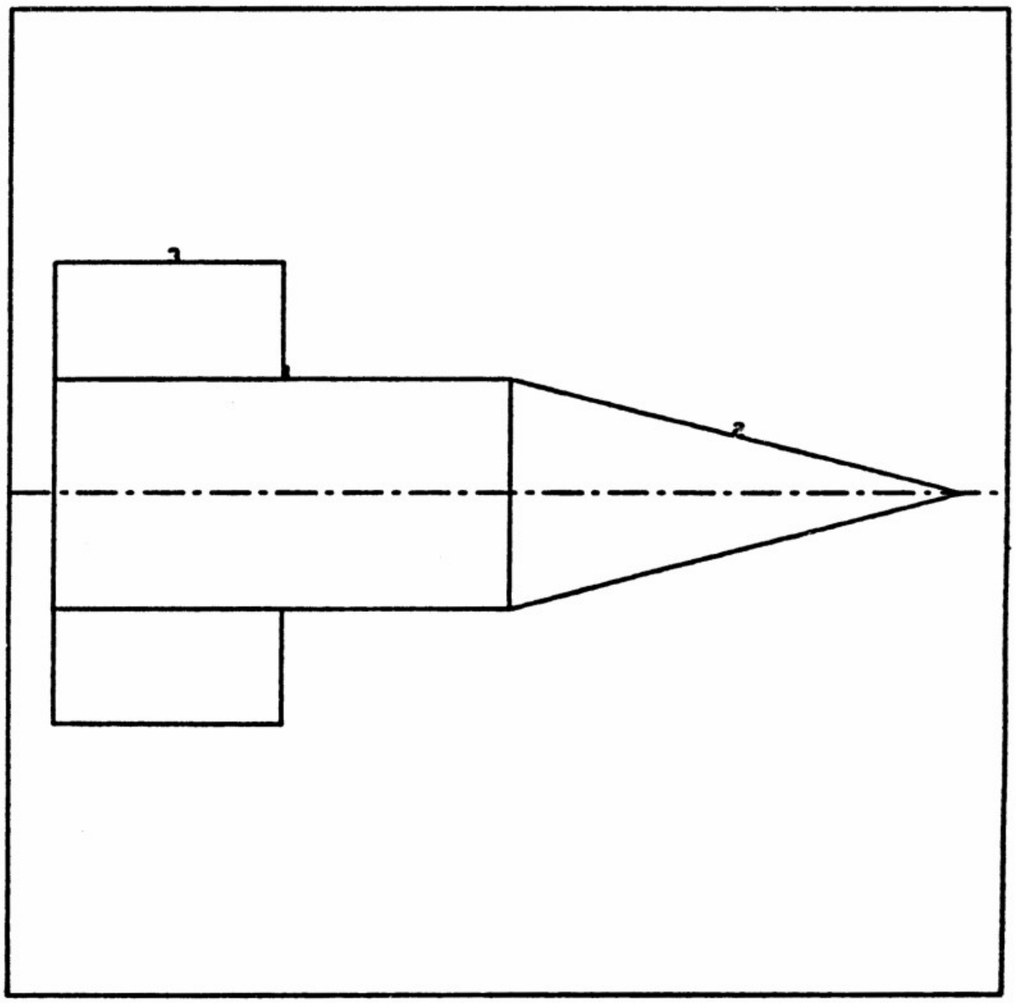


Figure 4. New Model-Finner

b. EF - Enter File

When the Enter Existing File module is selected, the program will prompt the user for a projectile model file name. If the name is not known, a list option is available. After typing EF the following instruction will be displayed:

Key in 9 character projectile title (or "LIST"): LIST

Lists may be formed in one of two methods:

Enter the type of list desired

1 - Brief
2 - Full

In the brief list only the file names are listed. In the full list the file description is printed in addition to the file names. Configurations which have been identified as inventory rounds will be accompanied by an asterisk (*).

After a file is selected the units to be used for the input/output are selected. The file contains a flag to show the units used at the time the file was cataloged. These units will be the default condition:

Enter number for the type of units to use for I/O
1 - English
2 - Metric
<cr> for default (english)

A drawing of the projectile (showing some key dimensions) will be created. The program will then accept a main menu option. A carriage return <cr> will return the program to a display of the main menu.

c. EE - Edit Existing

The Edit Existing module allows the user to make changes to the geometric representation of the projectile.

Upon entering this module, a drawing of the projectile identifying each element and the editing menu will be displayed, (Figure 5). A dashed line is drawn down the axis of the projectile. Element numbers that appear above this line have positive densities. The element numbers that appear below the line have negative densities.

Edit Option One allows the user to change the title and description for the model. If a projectile has been declared to be an inventory round, it is necessary to change the title in order to store any changes to the model.

Edit Option Two allows for the addition, deletion, or modification of element data. If this option is selected, the user will be prompted to enter an element number.

Edit Menu

1 File Title
2 Elements
3 Fin Information
4 Scale Model
5 Tabulate Model Data
6 Zoom
7 Change Units
8 Change Ref. Length
9 Change Element #
10 Change Ref. Dia.
11 Change Density
12 Mass Properties
99 Return to Main Menu
:

Filename: MAFSPIN

EE DEMONSTRATION

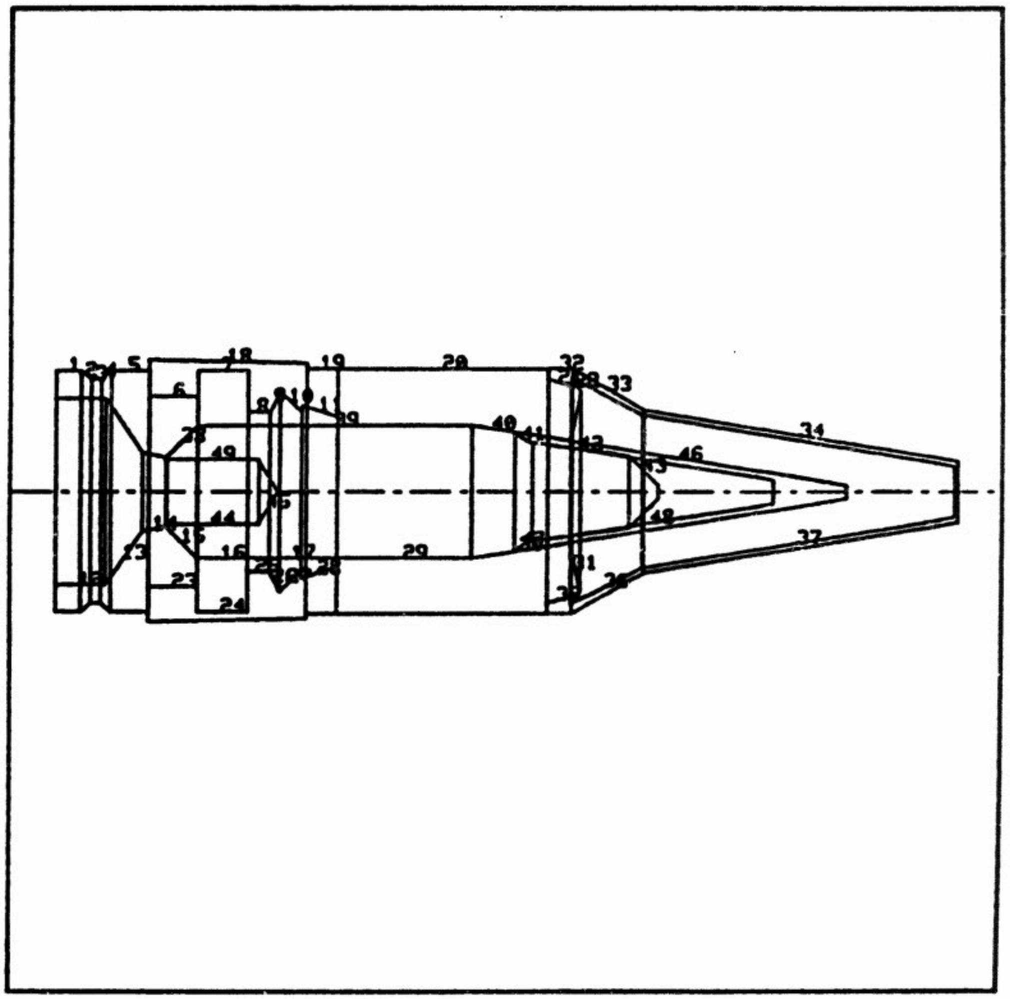


Figure 5. EE Option Menu

To delete an element, enter the element number as a negative. The model will then be redrawn. Be sure to examine the model before making additional changes. Since no gaps are left when numbering elements, some of the element numbers will now be changed.

To add elements enter the word ADD. The program will then display element numbers to be added and accept new geometry until a <cr> is entered with no data. Data is accepted in the same form as when the model was first entered; left diameter, right diameter, length, reference length, density, component code, radius, color code.

To modify an element, enter that element number. A menu will be displayed showing the current data (Figure 6).

Edit Option Three allows for modification of the fin information (Figure 7). Three entry menus are necessary to define fin data. In each case, the program will display the current data. A <cr> will leave the current data unchanged. The first display is the number of fin groups. Remember that the program is limited to three fin groups but stability analysis can only handle one fin group. In the second display, the elements make up the fin group. The program is limited to five elements in a fin group. The third display is the fin geometry. This data includes fin type, thickness of leading and trailing edges, projectile diameter at fin, and the number of fins.

Edit Option Four performs a scaling of all dimensions in the model. The user will be prompted for a scale factor. All lengths and diameters will be multiplied by this factor.

Edit Option Five creates a table of the mass properties of the current model and the element geometry of that model (Table 3). After the table is displayed, a full screen drawing of the projectile will be displayed (Figure 8). If a laser plotter is available, an option to make a print of this screen will be offered after a <cr> is typed.

Edit Option Six allows the user to zoom in on some portion of the screen to make a magnified view of the model. The terminal's cursor is used to locate two points. The first point will be the center of the new screen window. The second point will be the right edge of the screen. See Figures 9 and 10 for an example. Each terminal uses the cursor differently so check terminal instructions if problems occur. With most terminals a point is detected by typing <space bar> or typing <space bar> <cr>. To return to a full scale drawing, type <Z> instead of <space bar>.

Edit Option Seven will toggle the display units between english and metric.

```
   Edit Menu

 1 File Title
 2 Elements
 3 Fin Information
 4 Scale Model
 5 Tabulate Model Data
 6 Zoom
 7 Change Units
 8 Change Ref. Length
 9 Change Element #
10 Change Ref. Dia.
11 Change Density
12 Mass Properties
99 Return to Main Menu
: 2

Model has 49 elements
Enter element number
(Neg. elem. no. to delete)
(Type "ADD" to add element)
: 18
 Present values
1. Left Diam     (in)    1.055
2. Right Diam    (in)    1.025
3. El Length     (in)    0.640
4. Ref Length    (in)    0.380
5. Density(lbm/in3)      0.050
6. Component Code            3
7. Radius        (in)    0.000
8.  Color Code               0
 Enter variable no. "," value
 Enter "DONE" to continue
5,.055
DONE
```

Filename: MAFSPIN

EE DEMONSTRATION

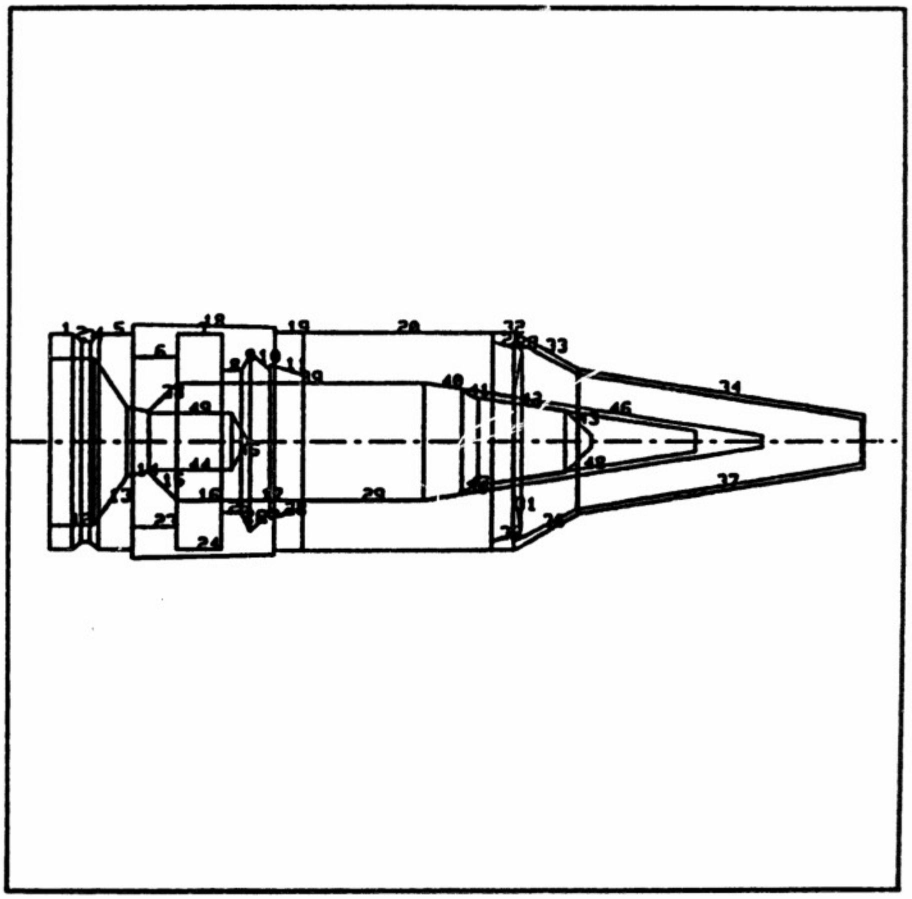


Figure 6. EE Element Modification

```
      Edit Menu

   1 File Title
   2 Elements
   3 Fin Information
   4 Scale Model
   5 Tabulate Model Data
   6 Zoom
   7 Change Units
   8 Change Ref. Length
   9 Change Element #
  10 Change Ref. Dia.
  11 Change Density
  12 Mass Properties
  99 Return to Main Menu
  : 3

  Enter number of fin groups
  (current model = 1):
  Enter element numbers in fin group 1
  (current model    28)
  :

  1 Fin Type                :       2
  2 Proj Dia at Fin    (in):   0.793
  3 Fin Thickness      (in):  0.0970
  4 Fin Lead Edge Thk  (in):  0.0800
  5 Number of Fins          :       6
   Enter variable no. "," value
   Enter "DONE" to continue
  D
```

Filename: MAFFIN

EE TEST

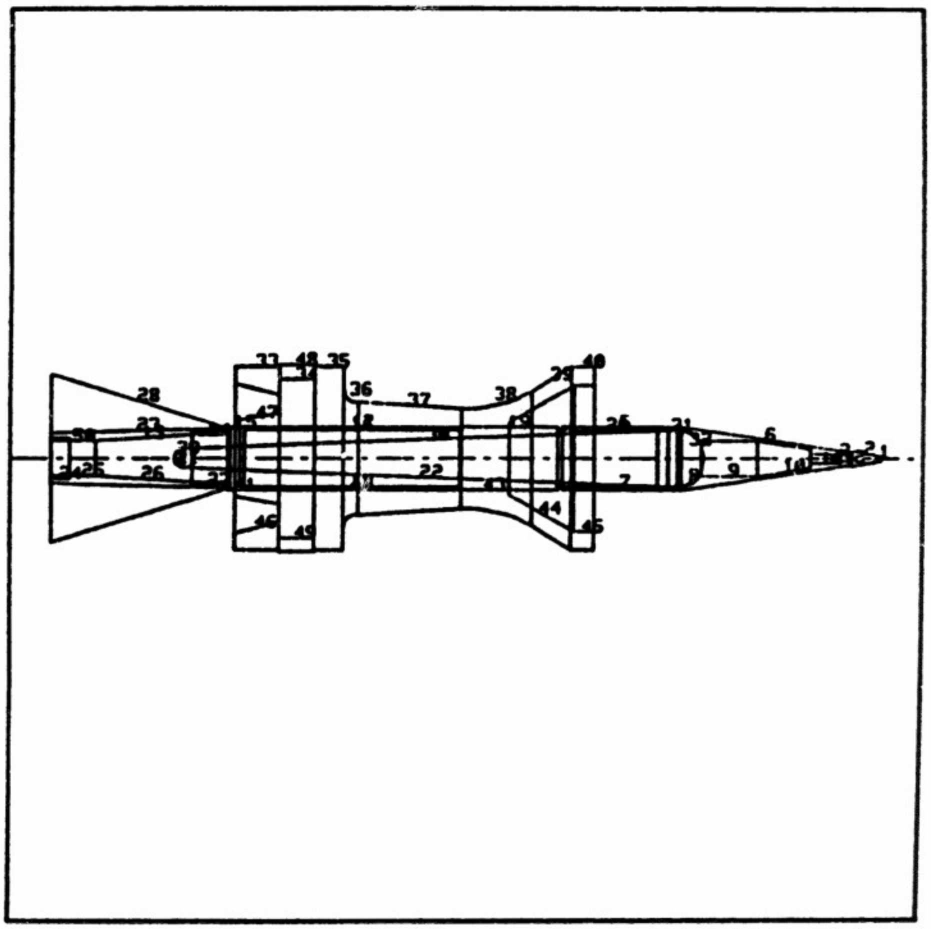


Figure 7. EE Fin Modification

TABLE 3. EE TABULATED OUTPUT

Filename: MAFSPIN :TEST EE MODEL

Diameter	(in):	0.531
Projectile Length	(in):	2.800
Ogive Length	(in):	1.550
C.G. from Nose	(in):	1.890
Axial Moment	(lbm-in**2):	0.00758
Transverse Moment	(lbm-in**2):	0.05857
Total Weight	(lbm):	0.298
Projectile Weight	(lbm):	0.230
Sabot Weight	(lbm):	0.067
Penetrator Weight	(lbm):	0.227
Filler Weight	(lbm):	0.000

Model Input Segment

Element No.	Left Diam. (in)	Right Diam. (in)	Elem Length (in)	Reference Pt (in)	Density (lbm/in3)	Code No.	Element Radius (in)	Color
1	0.9650	0.9650	0.1000	0.0000	0.1000	-1	0.00000	0
2	0.9650	0.9000	0.0400	0.1000	0.1000	-1	0.00000	0
3	0.9000	0.9000	0.0400	0.1400	0.1000	-1	0.00000	0
4	0.9000	0.9650	0.0400	0.1000	0.1000	-1	0.00000	0
5	0.9650	0.9650	0.1600	0.2200	0.1000	-1	0.00000	0
6	0.7600	0.7600	0.2000	0.3800	0.1000	-1	0.00000	0
7	0.9650	0.9650	0.2000	0.5000	0.1000	-1	0.00000	0
8	0.6400	0.6400	0.0900	0.7800	0.0800	-1	0.00000	0
9	0.6400	0.8000	0.0400	0.8700	0.0800	-1	0.00000	0
10	0.8000	0.6400	0.0900	0.9100	0.0800	-1	0.00000	0
11	0.7000	0.6000	0.1500	1.0000	0.0800	-1	0.00000	0
12	0.7450	0.7450	0.2000	0.0000	-0.1000	-1	0.00000	0
13	0.7450	0.3200	0.1560	0.2000	-0.1000	-1	0.00000	0
14	0.3200	0.2700	0.0940	0.3560	-0.1000	-1	0.00000	0
15	0.2700	0.5310	0.1300	0.4500	-0.1000	-1	0.00000	0
16	0.5310	0.5310	0.2000	0.5800	-0.1000	-1	0.00000	0
17	0.5310	0.5310	0.3700	0.7800	-0.1000	-1	0.00000	0
18	1.0550	1.0250	0.6400	0.3800	0.0500	3	0.00000	0
19	0.9800	0.9800	0.1300	1.0200	0.0500	-1	0.00000	0
20	0.9800	0.9880	0.8700	1.1500	0.0310	-1	0.00000	0
21	0.9000	0.0500	0.0900	2.0200	0.0500	-1	0.00000	0
22	0.8900	0.0100	0.0450	2.1100	0.0500	-1	0.00000	0
23	0.7600	0.7600	0.2000	0.3800	-0.0500	3	0.00000	0
24	0.9650	0.9650	0.2000	0.5800	-0.0500	3	0.00000	0
25	0.6400	0.6400	0.0900	0.7800	-0.0500	3	0.00000	0
26	0.6400	0.8000	0.0400	0.8700	-0.0500	-1	0.00000	0
27	0.8000	0.6400	0.0900	0.9100	-0.0500	-1	0.00000	0
28	0.7000	0.6000	0.1500	1.0000	-0.0500	-1	0.00000	0
29	0.5310	0.5310	0.5550	1.1500	-0.0350	-1	0.00000	0
30	0.5310	0.4100	0.4050	1.7050	-0.0350	-1	0.00000	0
31	0.4100	0.0100	0.0450	2.1100	-0.0500	-1	0.00000	0
32	0.9800	0.9800	0.1000	2.0200	0.0400	-1	0.00000	0
33	0.9800	0.6500	0.3000	2.1200	0.0400	-1	0.00000	0
34	0.6500	0.2400	1.3000	2.4200	0.0400	-1	0.00000	0
35	0.9000	0.8500	0.0900	2.0200	-0.0400	-1	0.00000	0
36	0.9200	0.6200	0.3000	2.1100	-0.0400	-1	0.00000	0
37	0.6200	0.2100	1.3000	2.4100	-0.0400	-1	0.00000	0
38	0.2800	0.5310	0.1250	0.4550	0.6850	1	0.00000	0
39	0.5310	0.5310	1.1250	0.5000	0.6850	1	0.00000	0
40	0.5310	0.4000	0.1750	1.7050	0.6850	4	0.00000	0
41	0.4600	0.3800	0.0750	1.0800	0.6850	1	0.00000	0
42	0.4000	0.2000	0.4000	1.9550	0.6850	1	0.00000	0
43	0.2800	0.0500	0.1250	2.3550	0.6850	1	0.00000	0
44	0.2550	0.2550	0.3750	0.4550	-0.6850	1	0.00000	0
45	0.2500	0.0000	0.0720	0.0300	-0.6850	1	0.00000	0
46	0.4800	0.0500	1.3750	1.8800	0.1000	4	0.00000	0
47	0.4600	0.3800	0.0750	1.8000	-0.1000	0	0.00000	0
48	0.4000	0.1000	1.0000	1.9550	-0.1000	0	0.00000	0
49	0.2550	0.2550	0.3750	0.4550	0.0600	0	0.00000	0

Return to continue

Codes
-2 Boom
-1 Sabot
0 Proj. Body
1 Penetrator
2 Filler
3 Band
4 Ogive
5 Boattail
6 Fin(rect/delt)

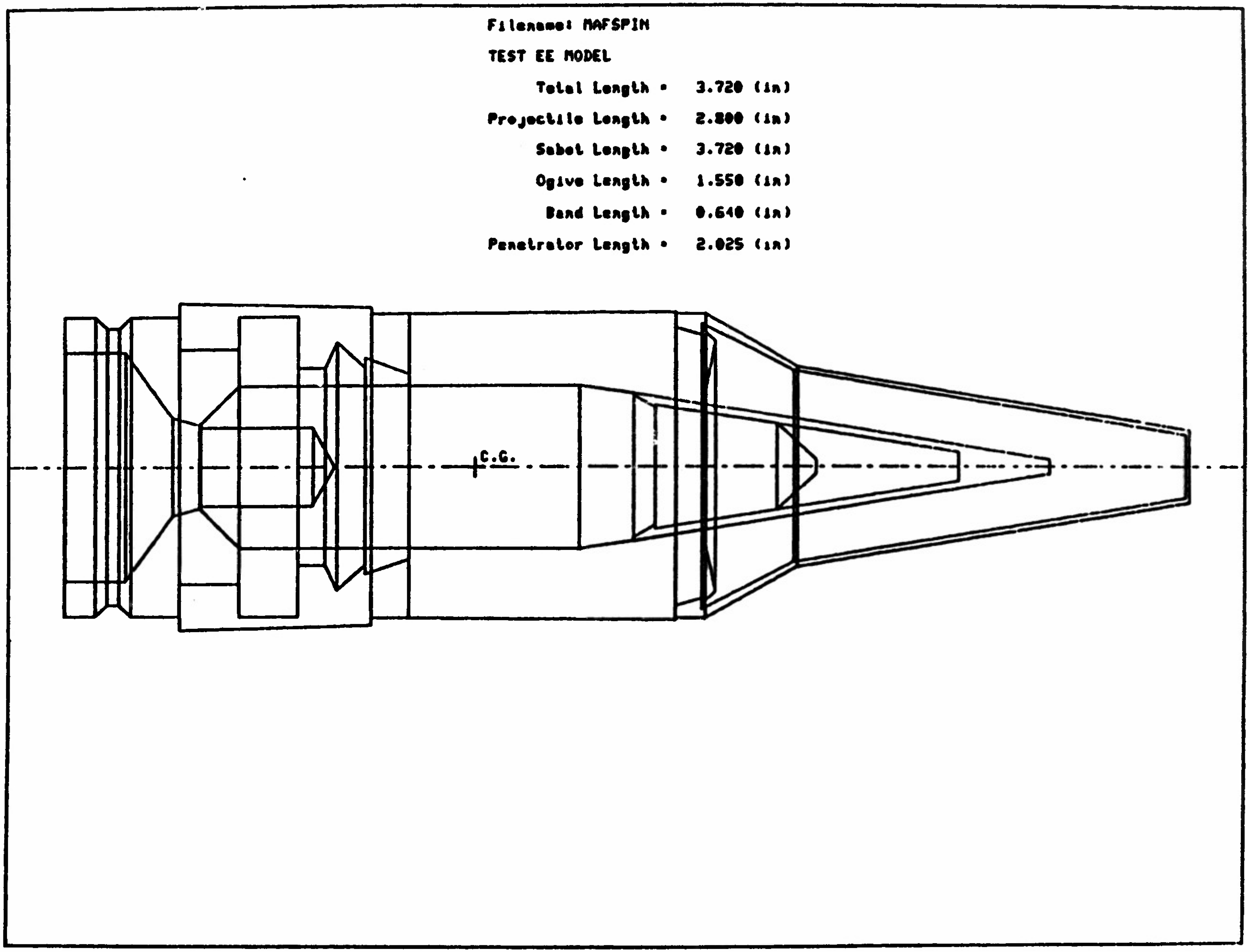


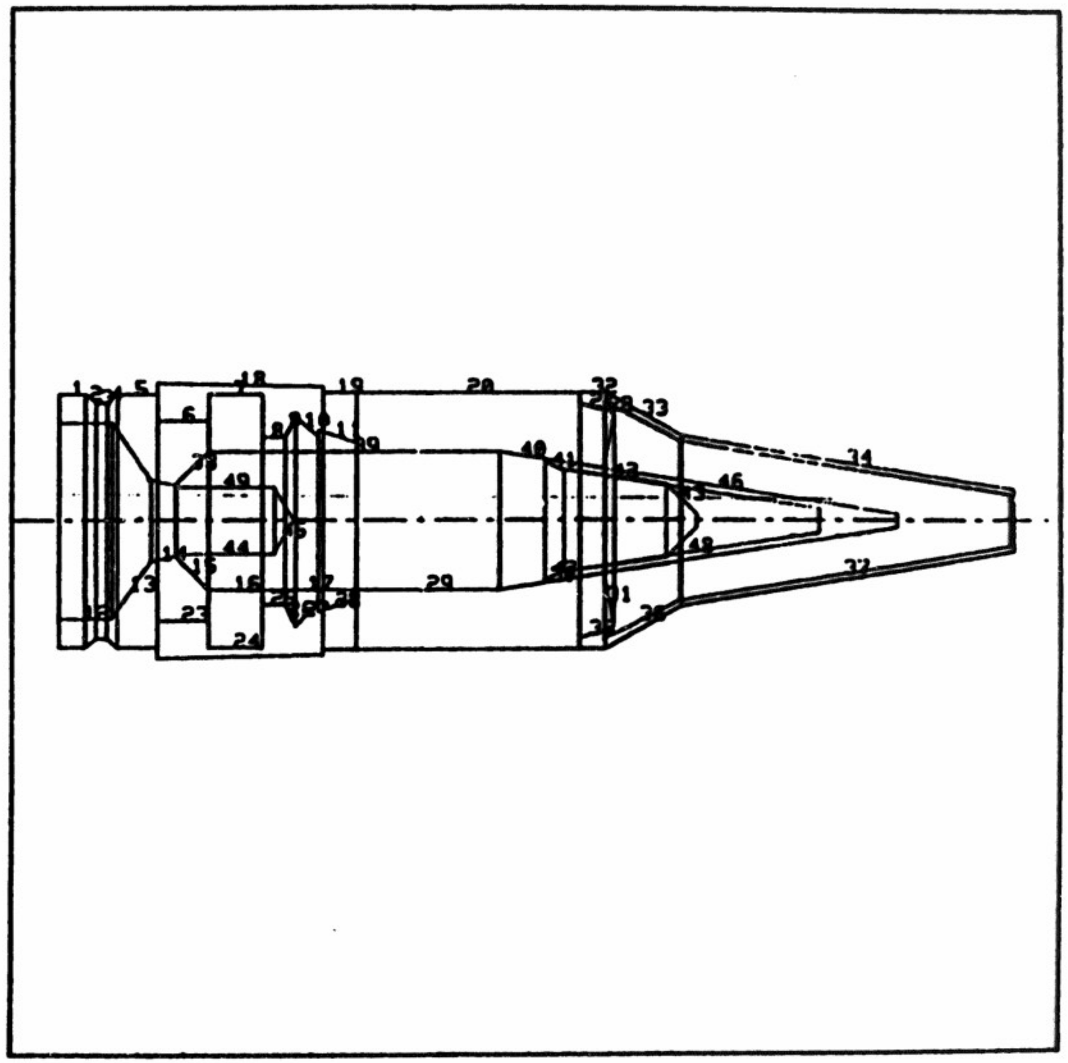
Figure 8. EE Projectile Drawing

Filename: I25MMAPDS

25MM M791 APDS-T

Edit Menu

1 File Title
2 Elements
3 Fin Information
4 Scale Model
5 Tabulate Model Data
6 Zoom
7 Change Units
8 Change Ref. Length
9 Change Element #
10 Change Ref. Dia.
11 Change Density
12 Mass Properties
99 Return to Main Menu
: 6



Please pick center location for the window
Enter "Z" to return to regular display

Now move crosshair to right side of window
Enter "Z" to return to regular display

Figure 9. EE Zoom Option

```
    Edit Menu

  1 File Title
  2 Elements
  3 Fin Information
  4 Scale Model
  5 Tabulate Model Data
  6 Zoom
  7 Change Units
  8 Change Ref. Length
  9 Change Element #
 10 Change Ref. Dia.
 11 Change Density
 12 Mass Properties
 99 Return to Main Menu
 : 8

Enter element method:
   1 By list
   2 By element range
   3 By ref. len range
   4 Return to edit menu
1
Enter list of elements
<CR> when done
: 1
:
Enter delta (in): 0.0
```

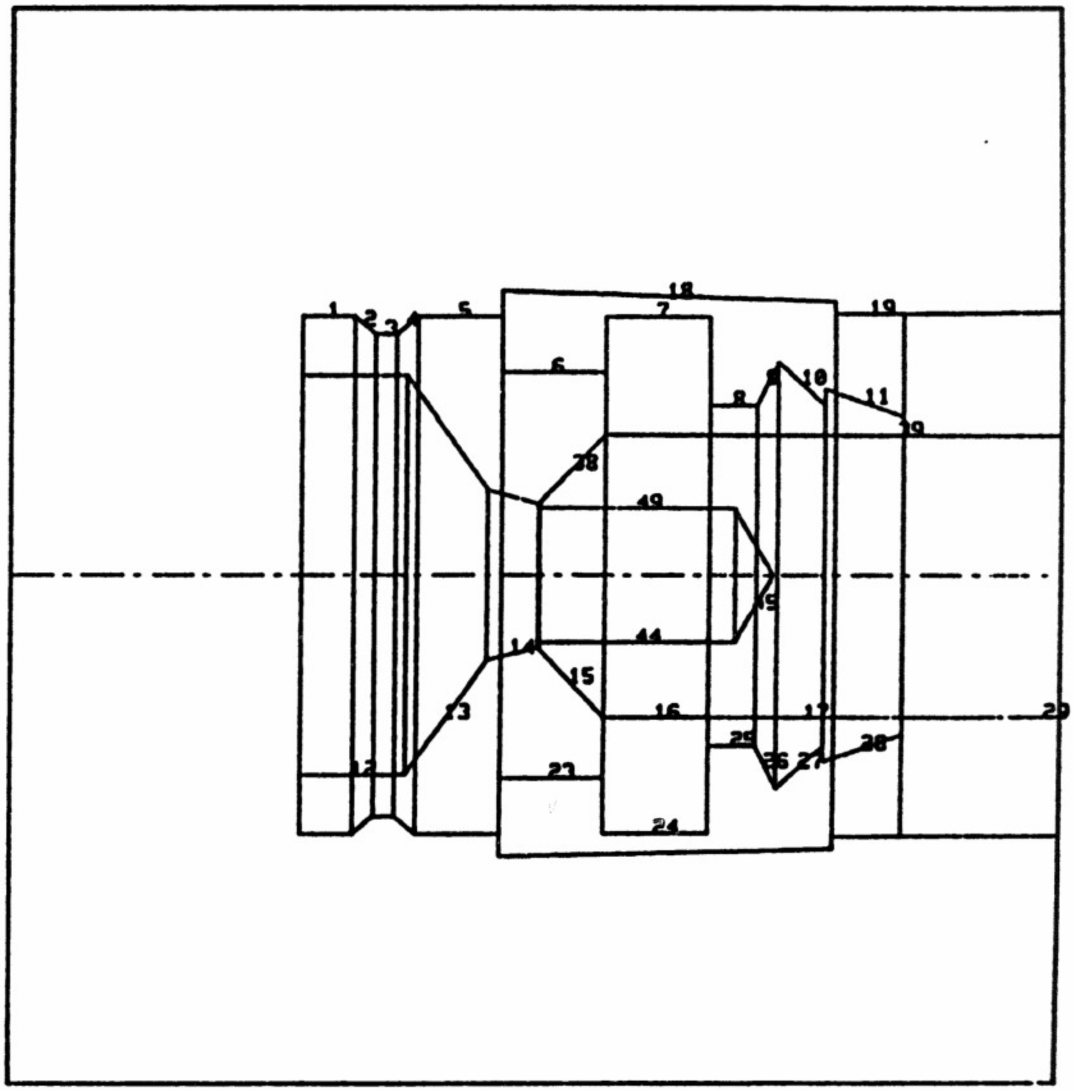


Figure 10. EE Reference Modification

Edit Option Eight allows for the modification of the reference length for a group of elements. Three methods exist for defining the elements to change (Figure 10). The first method is to enter a list of elements separated by commas. Element numbers will be accepted until a <cr> is entered with no elements. Method 2 accepts lower and upper numbers for a continuous range of elements. Again, multiple lines of input may be used, each with a continuous range. Method 3 accepts a range of reference lengths. Any element whose current reference length falls within this range will be modified.

Once the elements have been identified, enter the amount to change the reference length. A positive change will move the model to the right, a negative to the left. Remember that the model must not extend into negative space.

Edit Option Nine is used to swap the numbers of two elements. This is needed only to create a shaded color drawing on a Tektronix 4100 series terminal. Elements are drawn in numerical order. When operating in the color shaded mode, PRODAS draws each element as a color quadrilateral. Elements with a negative density are drawn with the background color. All other elements are drawn with the color selected by the user or assigned by the program. If the elements are not ordered properly, this could cause an element to be displayed before the negative element is displayed that makes room for it, i.e., the penetrator being draw before the sabot. This edit option allows for a quick reordering of elements to make a cleaner color drawing.

Edit Option Ten allows the user to assign a value to the reference diameter for the projectile. This will override any value computed from the geometry.

Edit Option Eleven allows the user to specify an old density and a new density. All occurrences of the old density will be changed to the new density. Note that positive and negative densities are never considered to be the same.

Edit Option Twelve computes and displays the mass properties of the projectile as it is currently defined.

Edit Option Ninety Nine returns the program to the main level.

d. Other Auxiliary Options

(1) C - Catalog

This program option will take the data representing the projectile model and the analysis input parameters and store them in a data file for use in the future. The data file will use the file name specified for the current projectile (see EN and EE options). If a file already exists by this name, the old file will be lost. If the inventory round flag was set for this model file the program will not allow the user to catalog the file without first changing the name (see EE option). The inventory round flag may only be set/cleared by the user using a system editor on the projectile model file. The flag may not be changed from within PRODAS.

When a file is cataloged, the program will examine the LIST.MAF data file. If an entry does not exist for this file name, an entry will be created.

(2) B - Bye (exit PRODAS)

This option is used to terminate a PRODAS session. The program maintains flags for the data that is available for storage. If this data has not been retained, the program will question the user to see if this data is to be saved before exit.

If the projectile model is not an inventoried round and an analysis module has been run that could have changed stored parameters, the user will be prompted to see if a catalog option is desired before exit.

(3) DF - Delete File

This option allows the user to delete projectile model files that have become outdated or surplused. The program will prompt the user to specify the files to be deleted. Continue specifying names until finished deleting files, then enter a <cr>. If the inventory flag has been set for a file, it may not be deleted. The LIST.MAF file will be updated to remove the entry for each file deleted.

e. M - Physical Properties

The physical properties segment calculates the weight, center of gravity, and moments of inertia for each element in the projectile model. Center of gravity locations are measured from the reference length for the element (positive right). These individual properties are then combined to form the properties for the entire composite projectile. Within the weight summaries, total refers to the sum of all elements (interior ballistic weight) and projectile refers to the flying portion of the model (exterior ballistic weight). Inertias do not include sabot elements; therefore, it is an exterior ballistic property. Depending on the projectile configuration, the sabot, penetrator, and HEI weights may be computed and tabulated separately. If fins are present on this model, the fin group information is displayed. Tables 4 and 5 show typical results for a spin and fin stabilized projectile.

The only input required for this segment is the projectile model data. The output from this segment is used by most of the other PRODAS modules.

Once the physical properties have been calculated, the user has the option of overriding the computed properties for individual elements or groups of elements. This is done by selecting the "MOD" option after the output has been displayed. If the "MOD" option is selected, enter the element number(s) to be changed. Then enter the weight, inertias, reference length, and center of gravity for the group of elements. These properties will be displayed as the first element given with the properties for the remaining elements zeroed.

TABLE 4. SPIN STABILIZED MOMENTS

Page Number 1

Filename: I25MMAPDS : 25MM M791 APDS-T

Diameter (in)	Projectile Length (in)	Ogive Length (in)	C.G. from Nose (in)	Axial Moment (lbm-in**2)	Transverse Moment (lbm-in**2)	Total Weight	Projectile Weight	Sabot Weight	Penetrator Weight	Filler Weight	
0.531	2.800	1.550	1.890	0.00758	0.05857	0.298	0.230	0.067	0.227	0.000	lbm
						2084.660	1613.995	470.665	1586.987	0.000	Grains
						135.030	104.543	30.486	102.794	0.000	Grams

I	Code	Left Diameter (in)	Right Diameter (in)	Length (in)	Reference Location (in)	Density (lbm/in**3)	Weight (lbm)	Axial Moment (lbm-in**2)	Transverse Moment (lbm-in**2)	Center of Gravity (in)	Radius (in)
1	-1	0.965	0.965	0.100	0.000	0.100	0.00731	0.00085	0.00043	0.0500	
2	-1	0.965	0.900	0.040	0.100	0.100	0.00273	0.00030	0.00015	0.0195	
3	-1	0.900	0.900	0.040	0.140	0.100	0.00254	0.00026	0.00013	0.0200	
4	-1	0.900	0.965	0.040	0.180	0.100	0.00273	0.00030	0.00015	0.0205	
5	-1	0.965	0.965	0.160	0.220	0.100	0.01170	0.00136	0.00071	0.0800	
6	-1	0.760	0.760	0.200	0.380	0.100	0.00907	0.00066	0.00036	0.1000	
7	-1	0.965	0.965	0.200	0.580	0.100	0.01463	0.00170	0.00090	0.1000	
8	-1	0.640	0.640	0.090	0.780	0.080	0.00232	0.00012	0.00006	0.0450	
9	-1	0.640	0.800	0.040	0.870	0.080	0.00131	0.00009	0.00004	0.0215	
10	-1	0.800	0.640	0.090	0.910	0.080	0.00294	0.00019	0.00010	0.0417	
11	-1	0.700	0.600	0.150	1.000	0.080	0.00399	0.00021	0.00011	0.0712	
12	-1	0.745	0.745	0.200	0.000	-0.100	-0.00872	-0.00060	-0.00033	0.1000	
13	-1	0.745	0.320	0.156	0.200	-0.100	-0.00366	-0.00016	-0.00009	0.0583	
14	-1	0.320	0.270	0.094	0.356	-0.100	-0.00064	-0.00001	0.00000	0.0444	
15	-1	0.270	0.531	0.130	0.450	-0.100	-0.00170	-0.00004	-0.00002	0.0786	
16	-1	0.531	0.531	0.200	0.580	-0.100	-0.00443	-0.00016	-0.00009	0.1000	
17	-1	0.531	0.531	0.370	0.780	-0.100	-0.00819	-0.00029	-0.00024	0.1850	
18	3	1.055	1.025	0.640	0.380	0.050	0.02719	0.00368	0.00277	0.3169	
19	-1	0.980	0.980	0.130	1.020	0.050	0.00490	0.00059	0.00030	0.0650	
20	-1	0.980	0.988	0.870	1.150	0.031	0.02051	0.00248	0.00253	0.4362	
21	-1	0.900	0.850	0.090	2.020	0.050	0.00271	0.00026	0.00013	0.0441	
22	-1	0.890	0.810	0.045	2.110	0.050	0.00128	0.00012	0.00006	0.0218	
23	3	0.760	0.760	0.200	0.380	-0.050	-0.00454	-0.00033	-0.00018	0.1000	
24	3	0.965	0.965	0.200	0.580	-0.050	-0.00731	-0.00085	-0.00045	0.1000	
25	3	0.640	0.640	0.090	0.780	-0.050	-0.00145	-0.00007	-0.00004	0.0450	
26	-1	0.640	0.800	0.040	0.870	-0.050	-0.00082	-0.00005	-0.00003	0.0215	
27	-1	0.800	0.640	0.090	0.910	-0.050	-0.00184	-0.00012	-0.00006	0.0417	
28	-1	0.700	0.600	0.150	1.000	-0.050	-0.00249	-0.00013	-0.00007	0.0712	
29	-1	0.531	0.531	0.555	1.150	-0.035	-0.00430	-0.00015	-0.00019	0.2775	
30	-1	0.531	0.410	0.405	1.705	-0.035	-0.00248	-0.00007	-0.00007	0.1852	
31	-1	0.410	0.810	0.045	2.110	-0.050	-0.00068	-0.00004	-0.00002	0.0272	
32	-1	0.980	0.980	0.100	2.020	0.040	0.00302	0.00036	0.00018	0.0500	
33	-1	0.980	0.650	0.300	2.120	0.040	0.00635	0.00056	0.00033	0.1300	
34	-1	0.650	0.240	1.300	2.420	0.040	0.00866	0.00029	0.00113	0.4636	
35	-1	0.900	0.850	0.090	2.020	-0.040	-0.00217	-0.00021	-0.00011	0.0441	
36	-1	0.920	0.620	0.300	2.110	-0.040	-0.00566	-0.00045	-0.00026	0.1308	
37	-1	0.620	0.210	1.300	2.410	-0.040	-0.00761	-0.00023	-0.00095	0.4520	
38	1	0.280	0.531	0.125	0.455	0.685	0.01141	0.00027	0.00015	0.0750	
39	1	0.531	0.531	1.125	0.580	0.685	0.17056	0.00601	0.02101	0.5625	
40	4	0.531	0.480	0.175	1.705	0.685	0.02408	0.00077	0.00045	0.0846	
41	1	0.460	0.380	0.075	1.880	0.685	0.00714	0.00016	0.00008	0.0351	
42	1	0.400	0.280	0.400	1.955	0.685	0.02514	0.00038	0.00052	0.1767	

TABLE 4. SPIN STABILIZED MOMENTS (CONCLUDED)

Page Number 2

Filename: I25MMAPDS 25MM M791 APDS-T

I	Code	Left Diameter (in)	Right Diameter (in)	Length (in)	Reference Location (in)	Density (lbm/in**3)	Weight (lbm)	Axial Moment (lbm-in**2)	Transverse Moment (lbm-in**2)	Center of Gravity (in)	Radius (in)
43	1	0.280	0.050	0.125	2.355	0.685	0.00213	0.00001	0.00001	0.0375	
44	1	0.255	0.255	0.375	0.455	-0.685	-0.01312	-0.00011	-0.00021	0.1875	
45	1	0.250	0.000	0.072	0.830	-0.685	-0.00081	0.00000	0.00000	0.0180	
46	4	0.480	0.050	1.375	1.880	0.100	0.00925	0.00016	0.00089	0.3826	
47	0	0.460	0.380	0.075	1.880	-0.100	-0.00104	-0.00002	-0.00001	0.0351	
48	0	0.400	0.100	1.000	1.955	-0.100	-0.00550	-0.00007	-0.00036	0.3214	
49	0	0.255	0.255	0.375	0.455	0.060	0.00115	0.00001	0.00002	0.1875	

Element Codes

-2 - Boom	-1 - Sabot	0 - Projectile Body
1 - Penetrator	2 - HE	3 - Band
4 - Ogive	5 - Boattail	6 - Fins
7 - Tracer		

TABLE 5. FIN STABILIZED MOMENTS

Filename: I120M829 :120MM M829 APDS-FS

Diameter (mm)	Projectile Length (mm)	Ogive Length (mm)	C.G. from Nose (mm)	Axial Moment (kg-cm**2)	Transverse Moment (kg-cm**2)	Total Weight	Projectile Weight	Sabot Weight	Penetrator Weight	Filler Weight	
26.492	613.969	91.618	325.514	3.80783	783.00452	15.751	9.386	6.365	8.862	0.000	lbm
						7144.427	4257.256	2887.171	4019.563	0.000	Grams

I	Code	Left Diameter (mm)	Right Diameter (mm)	Length (mm)	Reference Location (mm)	Density (gm/cm**3)	Weight (kg)	Axial Moment (kg-cm**2)	Transverse Moment (kg-cm**2)	Center of Gravity (mm)	Radius (mm)
1	-1	120.802	120.802	13.538	381.584	1.384	0.21475	3.91740	1.99150	6.7691	
2	-1	114.300	114.300	13.538	381.584	-1.384	-0.19225	-3.13965	-1.59919	6.7691	
3	3	116.510	120.599	7.620	215.468	1.384	0.11643	2.04654	1.02890	3.8538	
4	3	120.599	120.599	3.556	223.088	1.384	0.05622	1.02206	0.51162	1.7780	
5	3	118.212	118.212	6.350	226.644	1.384	0.09645	1.68480	0.84564	3.1750	
6	3	123.165	121.006	14.554	232.994	1.384	0.23580	4.39381	2.23853	7.2342	
7	3	121.006	121.006	35.560	247.548	1.384	0.56597	10.35902	5.77591	17.7800	
8	3	121.006	119.329	13.350	283.108	1.384	0.20971	3.78568	1.92403	6.6491	
9	3	112.141	112.141	39.167	215.468	-1.384	-0.53539	-8.41610	-4.89248	19.5834	
10	3	112.141	86.004	3.505	254.635	-1.384	-0.03761	-0.47484	-0.23780	1.5994	
11	3	86.004	80.086	8.128	258.140	-1.384	-0.06096	-0.52660	-0.26665	3.9675	
12	3	80.086	102.235	1.676	266.268	-1.384	-0.01522	-0.16395	-0.08101	0.9058	
13	3	102.235	102.235	2.692	267.945	-1.384	-0.03059	-0.39964	-0.20001	1.3462	
14	3	102.235	111.328	7.874	270.637	-1.384	-0.09765	-1.39601	-0.70304	4.0487	
15	3	104.318	113.106	7.620	278.511	-1.384	-0.09794	-1.45083	-0.73015	3.9126	
16	3	107.645	119.685	10.439	286.131	-1.384	-0.14674	-2.38094	-1.20376	5.4038	
17	-1	119.685	119.685	11.379	296.570	2.768	0.35436	6.34502	3.21074	5.6896	
18	-1	101.600	114.300	6.350	301.015	-2.768	-0.17187	-2.68161	-1.34646	3.2609	6.375
19	-1	114.300	114.300	0.584	307.365	-2.768	-0.01659	-0.27096	-0.13549	0.2921	
20	-1	101.600	70.256	15.900	301.015	2.768	0.21985	1.82492	0.95988	7.0482	-19.761
21	-1	70.256	66.777	11.633	316.916	2.768	0.11875	0.69760	0.36218	5.7182	
22	-1	66.777	82.829	30.683	328.549	2.768	0.33078	2.09263	1.31559	16.4908	-40.005
23	-1	82.829	109.322	16.967	359.232	2.768	0.34264	4.07813	2.11962	9.2585	
24	-1	109.322	114.300	1.219	376.199	2.768	0.03256	0.50023	0.25015	0.6168	-3.150
25	-1	119.380	119.380	4.216	377.419	2.768	0.13063	2.32720	1.16553	2.1082	
26	-1	114.300	114.300	13.538	381.635	2.768	0.38451	6.27929	3.19838	6.7691	
27	-1	119.380	119.380	1.778	395.173	2.768	0.05509	0.98135	0.49082	0.8890	
28	-1	68.986	81.128	2.540	367.792	-2.768	-0.03309	-0.24909	-0.12472	1.3216	8.509
29	-1	68.986	52.222	7.849	367.792	2.768	0.05399	0.21775	0.11173	3.6324	-8.484
30	-1	52.222	30.480	70.993	375.641	2.768	0.26998	0.64258	1.37581	29.4153	
31	-1	81.128	98.044	8.611	370.332	-2.768	-0.15068	-1.53404	-0.77624	4.5755	
32	-1	98.044	109.220	13.665	378.943	-2.768	-0.33245	-4.66756	-2.38459	7.0625	19.507
33	-1	109.220	109.220	7.137	392.608	-2.768	-0.18510	-2.76003	-1.38787	3.5687	
34	-1	30.480	30.480	3.175	446.634	2.768	0.00641	0.00745	0.00378	1.5875	
35	-1	119.380	115.468	2.794	396.951	2.768	0.08376	1.44432	0.72270	1.3815	
36	-1	24.511	24.511	111.430	119.456	-2.768	-0.14554	-0.10930	-1.56056	55.7149	
37	-1	25.730	25.730	218.923	230.886	-2.768	-0.31509	-0.26075	-12.71476	109.4613	
38	-1	30.226	34.696	2.286	115.011	7.833	0.01484	0.01971	0.00992	1.1954	
39	-1	34.696	34.696	10.719	117.297	7.833	0.07939	0.11946	0.06733	5.3594	
40	-1	22.708	28.296	4.445	115.011	-7.833	-0.01786	-0.01480	-0.00769	2.3842	
41	-1	29.997	29.997	8.560	119.456	-7.833	-0.04739	-0.05330	-0.02954	4.2799	
42	-1	29.489	29.489	4.750	119.456	2.768	0.00898	0.00976	0.00505	2.3749	

TABLE 5. FIN STABILIZED MOMENTS (CONCLUDED)

Filename: I120M829 :120MM M829 APDS-FS

I	Code	Left Diameter (mm)	Right Diameter (mm)	Length (mm)	Reference Location (mm)	Density (gm/cm**3)	Weight (kg)	Axial Moment (kg-cm**2)	Transverse Moment (kg-cm**2)	Center of Gravity (mm)	Radius (mm)
43	-1	29.489	64.541	129.870	124.206	2.768	0.65299	2.21028	9.05490	80.3580	
44	-1	64.541	102.235	16.561	254.076	2.768	0.19764	1.43686	0.76501	9.3433	-18.999
45	-1	102.235	111.328	7.874	270.637	2.768	0.19530	2.79202	1.40608	4.0487	
46	-1	104.318	113.106	7.620	278.511	2.768	0.19588	2.90166	1.46029	3.9126	
47	-1	107.645	119.685	10.439	286.131	2.768	0.29349	4.76187	2.40751	5.4038	
48	0	26.416	26.416	101.600	12.903	2.768	0.15413	0.13444	1.39305	50.8000	
49	6	81.509	81.509	25.146	0.000	2.768	0.03693	0.27648	0.15770	12.5730	
50	6	81.509	26.416	89.306	25.146	2.768	0.06992	0.34590	0.48277	31.6196	
51	6	41.275	26.416	12.903	0.000	-2.768	-0.00364	-0.00783	-0.00425	5.0428	
52	0	22.225	22.225	11.989	12.903	-2.768	-0.01287	-0.00795	-0.00552	5.9944	
53	0	19.558	19.558	13.157	24.892	-2.768	-0.01094	-0.00523	-0.00419	6.5786	
54	0	21.996	21.996	24.689	64.491	-2.768	-0.02597	-0.01571	-0.02104	12.3444	
55	0	23.012	23.012	25.298	89.179	-2.768	-0.02913	-0.01928	-0.02517	12.6492	
56	1	19.812	21.996	2.997	64.491	18.546	0.01909	0.01048	0.00538	1.5508	
57	1	21.996	21.996	25.984	67.488	18.546	0.18312	0.11075	0.15841	12.9921	
58	1	22.403	22.403	24.994	93.472	18.546	0.18271	0.11462	0.15243	12.4968	
59	1	24.511	24.511	112.420	118.466	18.546	0.98378	0.73880	10.73051	56.2102	
60	1	25.730	25.730	219.075	230.886	18.546	2.11256	1.74826	85.36569	109.5375	
61	1	25.730	24.308	0.711	449.961	18.546	0.00630	0.00479	0.00240	0.3503	-0.762
62	1	24.308	24.308	2.591	450.672	18.546	0.02230	0.01647	0.00836	1.2954	
63	1	24.308	21.361	36.881	453.263	18.546	0.28049	0.18408	0.40857	17.6484	
64	1	21.361	21.361	31.826	490.144	18.546	0.21153	0.12065	0.23888	15.9131	
65	0	26.492	24.892	72.009	450.342	2.768	0.10337	0.08543	0.48891	35.2572	
66	4	24.892	11.328	52.426	522.351	2.768	0.03913	0.01968	0.08737	19.9610	
67	4	11.557	0.762	39.192	574.777	7.833	0.01149	0.00115	0.00813	10.4812	
68	0	25.019	24.308	0.279	450.342	-2.768	-0.00037	-0.00028	-0.00014	0.1385	-0.762
69	0	24.308	24.308	2.591	450.672	-2.768	-0.00333	-0.00246	-0.00125	1.2954	
70	0	24.308	21.361	36.881	453.263	-2.768	-0.04186	-0.02748	-0.06098	17.6484	
71	0	21.361	21.361	31.826	490.144	-2.768	-0.03157	-0.01801	-0.03565	15.9131	
72	0	6.756	6.756	32.715	521.970	-2.768	-0.00325	-0.00019	-0.00299	16.3576	
73	0	8.077	8.077	20.091	554.685	-2.768	-0.00285	-0.00023	-0.00107	10.0457	
74	0	8.077	8.077	10.846	557.784	7.833	0.00435	0.00036	0.00060	5.4229	
75	0	6.985	6.985	6.147	568.630	7.833	0.00185	0.00011	0.00011	3.0734	

Fin Information

Fin Group	Element Numbers in Group	Fin Type	Thick (mm)	Lead Thk (mm)	Number of Fins
1	49 50 51	3	2.9972	2.0320	6

Element Codes

-2 - Boom	-1 - Sabot	0 - Projectile Body
1 - Penetrator	2 - HE	3 - Band
4 - Ogive	5 - Boattail	6 - Fins
7 - Tracer		

It must be noted that the weights and inertias given for the composite projectile are for the "flying" portion only. Sabot elements and rotating band elements on a saboted projectile are removed before making these calculations. The total weight is carried separately for use in the internal ballistics segment.

f. S - Stability

The stability segment is broken into three phases:

1 - Computation of aerodynamic and stability parameters

2 - Empirical interior ballistics

3 - Plotted/tabulated output

The form of the input and output menus will be different for spin and fin stabilized projectiles. Physical property data must be available from the "M" segment. The input menu for a spin stabilized projectile is:

Stability Inputs

1 -	Projectile Diameter	(inch):	0.531
2 -	Meplat Diameter	(inch):	0.050
3 -		(calibers):	0.094
4 -	Rotating Band Diameter	(inch):	0.531
5 -		(calibers):	1.000
6 -	Ogive Radius	(inch):	531.000
7 -		(calibers):	1000.000
8 -	Boom Length	(inch):	0.000
9 -		(calibers):	0.000
10 -	Projectile Length	(inch):	2.800
11 -		(calibers):	5.273
12 -	Ogive Length	(inch):	1.550
13 -		(calibers):	2.919
14 -	Boattail Length	(inch):	0.000
15 -		(calibers):	0.000
16 -	CG from Nose	(inch):	1.890
17 -		(calibers):	3.560
18 -	Rifling Twist	(inch/rev):	23.504
19 -		(calibers/rev):	23.862
20 -	Gun Bore Diameter	(inch):	0.985
21 -	Total Weight	(lbm):	0.230
22 -	Axial Moment	(lbm-in**2):	0.00758
23 -	Transverse Moment	(lbm-in**2):	0.05857
24 -	Air Temperature	(Deg F):	59.000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

The input menu for a fin stabilized projectile is:

```
Finned Projectile Aerodynamic Coefficient and
Stability Determination

 1 - Number of Fins                            :          6
 2 - Fin Type (1 Rectangular    2 Delta)       :          2
              (3 Clipped        4 Swept)
 3 - Fin Root Chord                 (calibers):      2.867
 4 - Fin Tip Chord                  (calibers):      0.000
 5 - Fin Height                     (calibers):      1.078
 6 - Fin Thickness                  (calibers):      0.070
 7 - Fin Lead Thickness             (calibers):      0.057
 8 - Boattail Length                (calibers):      2.867
 9 - Boom Length                    (calibers):      0.000
10 - Boom (or Aft Boattail) Dia     (calibers):      1.000
11 - Nose Radius                    (calibers):     30.535
12 - Meplat Diameter                (calibers):      0.043
13 - Nose Length                    (calibers):      3.308
14 - Nose to CG Distance            (calibers):      7.204
15 - Projectile Diameter               (inch):      1.395
16 - Projectile Cylindrical Length      (cal):      7.505
17 - Projectile Base to Fin Trailing           :      0.000
     Edge Distance (calibers)
18 - Axial Inertia                 (lbm-in**2):    1.64276
19 - Transverse Inertia            (lbm-in**2):  130.69066
20 - Weight                             (lbm):      8.206
21 - Projectile Velocity            (ft/sec):   5500.000
22 - Magnus Moment Coefficient                 :      5.000
23 - Roll Induced Side Moment Coefficient      :      0.000
24 - Temperature                      (Deg F):     59.000
25 - Gun Bore Diameter               (inches):      4.128
26 - Any T Pads on Fins       (0 - no 1 - yes):         0.

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

Note the SPINNER data may be entered in either length units or calibers but FINNER is limited to calibers only. A default ogive radius of 100 calibers is used if the ogive radius is set to zero. SPINNER requires that an ogive exists in order to run the stability analysis.

Within the "T" segment the aerodynamic coefficients may be modified to reflect any experimental data that becomes available. When this option is exercised a flag is set in PRODAS. If that flag is set when the stability segment is run, the user will be prompted with the message:

```
This round has previously modified aerodynamic coefficients.
Do you wish to recalculate the aerodynamic coefficients or
proceed directly to the stability analysis?

Enter 0 to recalculate aeros
Enter 1 to proceed directly to stability
```

If Option One is chosen, the values from the data base will be echoed in the output. If option zero is selected, or the empirical data has not been modified, a display of the flying (no sabot elements) portion of the projectile model together with the stability analysis model will be displayed. The stability analysis model is generated from the geometry as defined in the stability input menu. This drawing is displayed for the user to examine for model verification before running the analysis. Figure 11 shows the verification model for a typical FINNER analysis. In this figure both the projectile as modeled and the aerodynamic representation of that projectile are displayed. If the analysis model does not match the desired configuration, return to the input to correct the model. Once the user is satisfied with the model, the analysis will be run.

For both fin and spin stabilized projectiles, the tabulated output will include an echo of the input values, the table of aerodynamic coefficients, and the stability analysis parameters. For a spin stabilized projectile, a table of McDRAG coefficients will also be printed. Table 6 shows the output for a spin stabilized projectile. The parameters output in this table are:

<u>SPINNER aerodynamic coefficients are</u>:

Mach - Mach number

CX - Zero yaw drag coefficient

CX2 - Yaw drag coefficient per $\sin^2$

CNa - Normal force coefficient per sin

Cma - Pitching moment coefficient per sin

CPN - Normal force center of pressure (calibers from nose)

Cypa - Magnus force coefficient derivative per sin

Cnpa - Zero yaw magnus moment coefficient derivative per sin

Cnpa3- Cubic magnus moment coefficient derivative per $\sin^3$

Cnpa5- Quintic magnus moment coefficient derivative per $\sin^5$

CPF1 - Center of pressure of Magnus force at 1 degree of yaw (calibers from nose)

CPF5 - Center of pressure of Magnus force at 5 degrees of yaw (calibers from nose)

Cnpa-5- 5 degree secant slope of magnus moment coefficient derivative (@ 5 deg yaw) per sin a

Cmq - Pitch damping coefficient

Clp - Spin deceleration coefficient

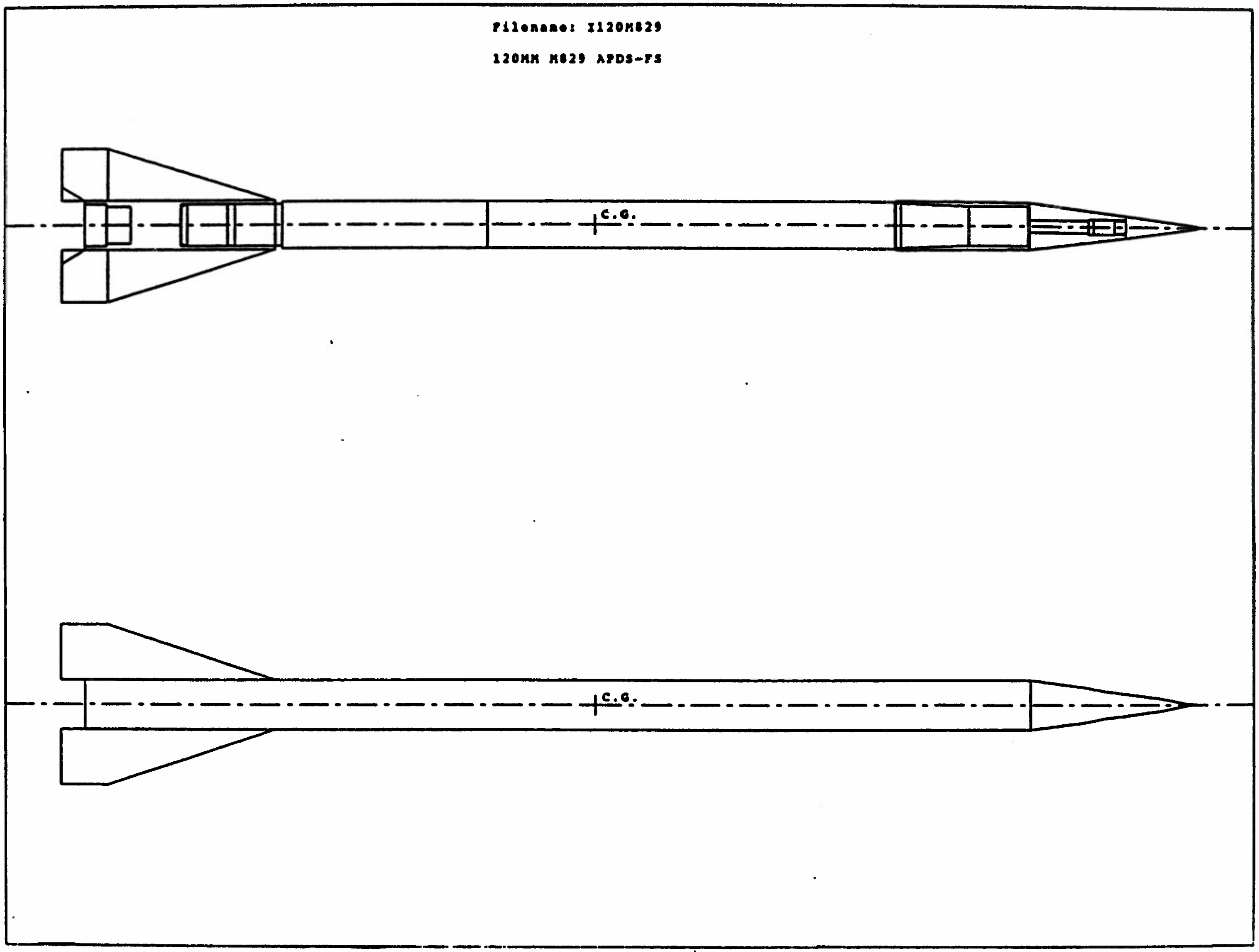


Figure 11. Geometry Validation Model

TABLE 6. SPINNER OUTPUT

Filename: I25MMAPDS 25MM M791 APDS-T

Stability Results

	Projectile Length	Ogive Length	Boattail Length	Boom Length	C.G. from Nose	Band Diameter	Meplat Diameter	Ogive Radius	Rifling Twist
in Inches	2.800	1.550	0.000	0.000	1.890	0.531	0.050	531.000	23.504/rev
in calibers	5.273	2.919	0.000	0.000	3.560	1.000	0.094	1000.000	23.862/rev

Diameter (in)	Weight (lbm)	Gun Bore (in)	Temperature (Deg F)	Air Density (slugs/ft**3)	Axial Mom. (lbm-in**2)	Trans. Mom. (lbm-in**2)
0.531	0.230	0.985	59.000	0.002376	0.00758	0.05857

Aerodynamic Coefficients

Spinner Prediction

Mach	CX	CX2	CNa	Cma	CPN	CYpa	Cnpa	Cnpa3	Cnpa5	CPF-1	CPF-5	Cnpa-5	Cmq	Clp
0.010	0.198	2.336	2.260	2.843	2.303	-0.844	-0.806	102.701	-989.512	2.605	3.705	0.122	-3.157	-0.027
0.600	0.198	2.336	2.260	2.865	2.293	-0.844	-0.806	102.701	-989.512	2.605	3.705	0.122	-3.157	-0.027
0.800	0.200	2.777	2.280	2.936	2.273	-0.844	-0.637	93.327	-895.768	2.805	3.805	0.206	-3.157	-0.026
0.900	0.220	3.207	2.311	2.888	2.310	-0.949	-0.337	68.133	-643.832	3.205	3.855	0.280	-6.443	-0.024
0.950	0.258	3.648	2.331	2.889	2.321	-1.213	-0.067	53.486	-497.359	3.505	3.905	0.418	-9.399	-0.024
1.000	0.371	4.126	2.356	2.881	2.338	-1.107	0.050	36.495	-327.448	3.605	3.905	0.382	-14.087	-0.023
1.050	0.427	4.577	2.409	2.613	2.476	-1.002	0.145	21.847	-180.974	3.705	3.905	0.345	-14.424	-0.023
1.100	0.418	5.068	2.421	2.686	2.451	-0.949	0.185	15.403	-116.525	3.755	3.905	0.327	-16.711	-0.023
1.200	0.392	5.570	2.465	2.759	2.441	-0.844	0.190	10.833	-70.826	3.785	3.905	0.291	-19.198	-0.022
1.350	0.367	5.004	2.532	2.795	2.456	-0.844	0.206	8.958	-52.077	3.805	3.905	0.291	-22.102	-0.021
1.500	0.346	4.418	2.618	2.826	2.481	-0.844	0.215	8.020	-42.702	3.815	3.905	0.291	-26.125	-0.020
1.750	0.313	3.818	2.717	2.856	2.509	-0.844	0.223	7.083	-33.328	3.825	3.905	0.291	-26.125	-0.019
2.000	0.283	3.239	2.796	2.834	2.547	-0.844	0.232	6.145	-23.954	3.835	3.905	0.291	-26.125	-0.020
2.500	0.230	2.760	2.854	2.851	2.561	-0.844	0.240	5.208	-14.579	3.845	3.905	0.291	-26.125	-0.019
3.000	0.190	2.349	2.762	2.877	2.518	-0.844	0.249	4.271	-5.205	3.855	3.905	0.291	-26.125	-0.018
4.000	0.152	1.945	2.662	2.853	2.488	-0.844	0.249	4.271	-5.205	3.855	3.905	0.291	-26.125	-0.017
5.000	0.130	1.542	2.562	2.822	2.458	-0.844	0.249	4.271	-5.205	3.855	3.905	0.291	-26.125	-0.017

TABLE 6. SPINNER OUTPUT (CONCLUDED)

Filename: I25MMAPDS   25MM M791 APDS-T

MCDRAG Computed Drag Coefficients

Mach	CD0	CX	DELTA	CDH	CDSF	CDBND	CDBT	CDB
0.010	0.232	0.198	0.034	0.000	0.070	0.000	0.000	0.162
0.600	0.234	0.198	0.036	0.000	0.067	0.000	0.000	0.166
0.800	0.238	0.200	0.037	0.000	0.063	0.000	0.000	0.175
0.900	0.240	0.220	0.020	0.000	0.061	0.000	0.000	0.179
0.950	0.265	0.258	0.006	0.024	0.060	0.000	0.000	0.181
1.000	0.330	0.371	-0.041	0.047	0.059	0.000	0.000	0.224
1.050	0.447	0.427	0.020	0.167	0.058	0.000	0.000	0.222
1.100	0.424	0.418	0.006	0.147	0.057	0.000	0.000	0.220
1.200	0.402	0.392	0.010	0.130	0.056	0.000	0.000	0.216
1.350	0.381	0.367	0.013	0.118	0.053	0.000	0.000	0.209
1.500	0.363	0.346	0.017	0.111	0.051	0.000	0.000	0.201
1.750	0.337	0.313	0.024	0.102	0.048	0.000	0.000	0.187
2.000	0.312	0.283	0.030	0.096	0.046	0.000	0.000	0.171
2.500	0.268	0.230	0.038	0.088	0.041	0.000	0.000	0.140
3.000	0.232	0.190	0.042	0.082	0.037	0.000	0.000	0.113
4.000	0.179	0.152	0.027	0.074	0.031	0.000	0.000	0.074
5.000	0.146	0.130	0.016	0.069	0.026	0.000	0.000	0.051

*** CX is either Spinner or modified drag ***
*** coefficient as presented in the above table ***

Filename: I25MMAPDS   25MM M791 APDS-T

Stability Parameters

Mach	GYRO	SBAR	RECIP	SBAR-5	RECIP-5	Spin (rad/sec)	DELT (sec)	W1 (rad/sec)	W2 (rad/sec)	L1 (1/ft)	L2 (1/ft)	L1-5 (1/ft)	L2-5 (1/ft)	DISP (mrad)
0.010	2.376	-0.753	-0.482	1.399	1.190	36.	0.0769	4.08	0.55	-0.001584	0.000561	-0.000251	-0.000772	0.065
0.600	2.357	-0.753	-0.482	1.399	1.189	2149.	0.0013	244.67	33.56	-0.001587	0.000564	-0.000250	-0.000773	0.064
0.800	2.300	-0.350	-1.216	1.594	1.544	2866.	0.0010	324.94	46.03	-0.001351	0.000323	-0.000124	-0.000904	0.063
0.900	2.338	0.232	2.435	1.183	1.035	3224.	0.0009	366.54	50.81	-0.001451	-0.000050	-0.000559	-0.000942	0.065
0.950	2.338	0.497	1.339	1.076	1.006	3403.	0.0008	386.89	53.64	-0.001545	-0.000379	-0.000844	-0.001080	0.064
1.000	2.344	0.453	1.427	0.746	1.069	3582.	0.0008	407.44	56.28	-0.002145	-0.000449	-0.001665	-0.000929	0.061
1.050	2.584	0.527	1.288	0.701	1.098	3762.	0.0007	434.07	52.84	-0.002036	-0.000619	-0.001756	-0.000899	0.068
1.100	2.514	0.500	1.333	0.609	1.180	3941.	0.0007	452.97	57.12	-0.002356	-0.000626	-0.002156	-0.000826	0.066
1.200	2.448	0.457	1.418	0.526	1.290	4299.	0.0006	492.22	64.34	-0.002760	-0.000585	-0.002616	-0.000729	0.067
1.350	2.416	0.425	1.493	0.476	1.379	4836.	0.0006	552.65	73.37	-0.003212	-0.000561	-0.003092	-0.000681	0.069
1.500	2.390	0.383	1.615	0.422	1.502	5374.	0.0005	613.00	82.58	-0.003860	-0.000504	-0.003751	-0.000613	0.072
1.750	2.364	0.400	1.563	0.434	1.471	6269.	0.0004	713.98	97.53	-0.003850	-0.000539	-0.003753	-0.000636	0.075
2.000	2.383	0.414	1.522	0.444	1.447	7165.	0.0004	816.98	110.46	-0.003830	-0.000579	-0.003746	-0.000664	0.079
2.500	2.369	0.429	1.484	0.454	1.424	8956.	0.0003	1020.27	139.03	-0.003819	-0.000605	-0.003747	-0.000678	0.082
3.000	2.347	0.428	1.486	0.449	1.435	10747.	0.0003	1222.56	168.60	-0.003816	-0.000584	-0.003755	-0.000645	0.080
4.000	2.367	0.422	1.501	0.444	1.448	14330.	0.0002	1632.28	222.60	-0.003815	-0.000560	-0.003755	-0.000621	0.078
5.000	2.393	0.415	1.520	0.436	1.465	17912.	0.0002	2043.77	274.83	-0.003813	-0.000537	-0.003753	-0.000597	0.077

<u>McDRAG aerodynamic coefficients are:</u>

MACH - Mach number

CDO - McDRAG computed zero yaw drag coefficient

CX - SPINNER computed zero yaw drag coefficient

DELTA- Difference between McDRAG and SPINNER

CDH - Transonic pressure head drag

CDSF - Skin friction drag

CDBND- Rotating band drag

CDBT - Boattail drag

CDB - Base drag

<u>SPINNER stability analysis parameters are:</u>

MACH - Mach number

GYRO - Gyro stability factor

SBAR - Dynamic stability factor @ 1 degree of yaw

RECIP- Dynamic reciprocal factor @ 1 degree of yaw

SBAR5- Dynamic stability factor @ 5 degrees of yaw

RECIP5- Dynamic reciprocal factor @ 5 degrees of yaw

SPIN - Spin rate (rad/sec)

W1 - Nutation frequency (rad/sec)

W2 - Precession frequency (rad/sec)

L1 - Nutation damping factor @ 1 degree of yaw (1/ft)

L2 - Precession damping factor @ 1 degree of yaw (1/ft)

L1-5 - Nutation damping factor @ 5 degrees of yaw (1/ft)

L2-5 - Precession damping factor @ 5 degrees of yaw (1/ft)

DELT - Integration time step (sec)

DISP - Dispersion factor per .001 inches of barrel clearance (mils)

Table 7 shows the tabulated output from a FINNER analysis. The parameters output are:

<u>FINNER aerodynamic coefficients are:</u>

Mach - Mach number

CD - Zero yaw drag coefficient

CNa - Normal force coefficient per sin $\bar{\alpha}$

CPN - Normal force center of pressure (calibers from nose)

Cma - Pitching moment coefficient per sin $\bar{\alpha}$

Cmq - Pitch damping coefficient

CXB - Body alone zero yaw axial force coefficient

CXF - Fin alone zero yaw axial force coefficient

CnaB - Body alone normal force coefficient per sin $\bar{\alpha}$

CnaF - Fin alone normal force coefficient per sin $\bar{\alpha}$

CPNB - Body alone normal force center of pressure (calibers from nose)

CPNF - Fin alone normal force center of pressure (calibers from nose)

<u>FINNER stability analysis parameters are:</u>

P - Spin rate (rad/sec)

GYRO - Gyro stability factor

SIGMA- Inverse of the gyro stability factor

RATE - $2\sigma/(1-\sigma)$ rate of nutation wrt precession divided by the rate of precession

P/W1 - Spin divided by the nutation frequency

PD/2V- Non-dimensional spin rate

W1 - Nutation frequency (rad/sec)

W2 - Precession frequency (rad/sec)

L1 - Nutation damping factor (1/ft)

TABLE 7. FINNER OUTPUT

Filename I120M829

	Body Length	Ogive Length	Boattail Length	Boom Length	C.G. from Nose	Band Diameter	Meplat Diameter	Ogive Radius
in mm	601.066	91.618	0.000	0.000	325.514	0.000	0.054	0.000
in calibers	22.220	3.387	0.000	0.000	12.033	0.000	0.002	0.000

Diameter (mm)	Weight (kg)	Gun Bore (mm)	Temperature (Deg C)	Air Density (gm/cm**3)	Axial Mom. (kg-cm**2)	Trans. Mom. (kg-cm**2)
27.051	4.257	120.015	15.000	0.631401	3.807829	783.004517

	Fin Root Chord	Fin Tip Chord	Fin Height	Fin Thickness	Fin Lead Thickness	Base to Trailing Edge Distance
in mm	114.452	25.146	29.502	2.997	2.032	-12.903
in calibers	4.231	0.930	1.091	0.111	0.075	-0.477

Projectile has 6 clipped delta fins

Aerodynamic Coefficients

Mach	CD	Cna	CPN	Cma	Cmq	CXB	CXF	CnaB	CnaF	CPNB	CPNF
0.010	0.459	20.551	18.363	-130.083	-3384.38	0.300	0.159	2.994	17.557	4.273	20.766
0.400	0.459	20.153	18.199	-124.249	-3242.55	0.300	0.159	2.994	17.160	4.266	20.629
0.800	0.538	24.545	18.615	-161.533	-3886.30	0.303	0.236	3.014	21.531	4.243	20.626
1.000	0.828	25.378	18.678	-168.633	-4020.44	0.480	0.348	3.060	22.319	4.031	20.686
1.100	0.819	26.236	18.997	-182.683	-4303.35	0.506	0.313	2.929	23.306	4.237	20.852
1.200	0.740	26.332	18.991	-183.201	-4353.49	0.477	0.263	2.982	23.350	4.168	20.883
1.300	0.707	26.213	18.970	-181.826	-4380.25	0.464	0.243	3.034	23.179	4.105	20.916
1.500	0.661	25.657	18.872	-175.459	-4384.03	0.438	0.223	3.159	22.498	3.979	20.963
1.800	0.595	25.604	18.811	-173.535	-4441.49	0.400	0.195	3.285	22.319	3.791	21.022
2.000	0.551	24.808	18.693	-165.206	-4348.91	0.376	0.175	3.371	21.437	3.683	21.053
2.500	0.481	23.933	18.521	-155.269	-4260.90	0.326	0.155	3.485	20.448	3.344	21.108
3.000	0.423	22.116	18.294	-138.452	-3980.63	0.288	0.135	3.449	18.667	2.959	21.127
3.500	0.391	20.244	18.080	-122.405	-3667.38	0.269	0.122	3.399	16.845	2.944	21.134
4.000	0.366	18.597	17.860	-108.359	-3389.68	0.250	0.116	3.349	15.248	2.929	21.140
5.000	0.338	16.145	17.473	-87.821	-2953.41	0.229	0.110	3.249	12.896	2.899	21.145

TABLE 7. FINNER OUTPUT (CONCLUDED)

Filename: I120M829

120MM M829 APDS-FS

Stability Parameters of Statically Stable Missiles

P (rad/sec)	GYRO	SIGMA	RATE	P/W1	PD/2V	W1 (rad/sec)	W2 (rad/sec)	L1 (1/m)	L2 (1/m)	AF	YR (deg)
13.841	0.000	4102.592	-2.000	0.100	0.000	138.110	-138.043	-0.0028	-0.0028	1.009	0.000
69.207	0.000	820.519	-2.002	0.501	0.001	138.245	-137.909	-0.0028	-0.0028	1.330	0.000
110.731	0.000	512.825	-2.004	0.800	0.001	138.346	-137.808	-0.0028	-0.0028	2.739	0.000
124.572	0.000	455.845	-2.004	0.900	0.001	138.380	-137.774	-0.0028	-0.0028	4.986	0.000
131.493	0.000	431.853	-2.005	0.950	0.001	138.397	-137.757	-0.0028	-0.0028	8.498	0.000
138.414	0.000	410.260	-2.005	1.000	0.001	138.414	-137.741	-0.0028	-0.0028	14.802	0.000
145.334	0.000	390.724	-2.005	1.050	0.001	138.431	-137.724	-0.0028	-0.0028	8.083	0.000
152.255	0.000	372.964	-2.005	1.100	0.001	138.448	-137.707	-0.0028	-0.0028	4.511	0.000
166.097	0.000	341.884	-2.006	1.199	0.001	138.481	-137.674	-0.0028	-0.0028	2.241	0.000
207.621	0.000	273.508	-2.007	1.498	0.002	138.583	-137.573	-0.0028	-0.0028	0.798	0.000
276.828	0.000	205.132	-2.010	1.995	0.002	138.752	-137.405	-0.0028	-0.0028	0.333	0.000
415.241	0.000	136.757	-2.015	2.985	0.003	139.090	-137.071	-0.0028	-0.0028	0.125	0.000
692.069	0.000	82.058	-2.025	4.951	0.006	139.770	-136.404	-0.0028	-0.0028	0.042	0.000
1384.138	-0.001	41.038	-2.050	9.783	0.011	141.483	-134.752	-0.0028	-0.0027	0.010	0.000
2768.275	-0.002	20.537	-2.102	19.095	0.022	144.972	-131.510	-0.0029	-0.0027	0.003	0.000
4152.413	-0.005	13.712	-2.157	27.954	0.034	148.542	-128.349	-0.0029	-0.0027	0.001	0.000
8304.825	-0.021	6.910	-2.338	51.990	0.067	159.739	-119.352	-0.0030	-0.0025	0.000	0.001

Stability Analyzed for

Velocity (m/sec)	CD	CNA	CMA	CMQ
1670.000	0.442	13.529	-56.233	-2711.642

FINNER stability analysis parameters - (continued)

L2 - Precession damping factor (1/ft)

AF - Amplification factor

YR - Yaw of repose (deg)

Additional outputs on this page include:

For rectangular fines:

AR- Fin aspect ratio

LAMBDA- Body diameter divided by total fin span (tip to tip)

For delta, clipped delta, or swept fins:

Epsilon - Angle from horizontal to a line between forward point of root chord to aft point of tip chord

LAMBDA - Body diameter divided by total fin span (tip to tip)

Once the aerodynamic coefficients and parameters have been printed, the user will be asked to select a muzzle velocity and aircraft velocity:

```
1 - Muzzle Velocity  (ft/sec):     4350.000
2 - Aircraft Velocity(ft/sec):        0.000

Key in item number "," new value
Key in "CALC" to calculate
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

The aircraft velocity may be zero but the muzzle velocity must be greater than zero. Since the muzzle velocity is used to compute the projectile spin, the velocity components must be dealt with separately.

The user may select the option "CALC" which will cause PRODAS to branch into the Empirical Interior Ballistic program. The Empirical Interior Ballistics input menu is:

```
1 - Peak Pressure              (psi):   60000.0000
2 - Barrel Length               (in):      64.0000
3 - Propellant Weight       (grains):    1569.4000
or
4 - Load Density         (lbm/in**3):       0.0380
5 - Chamber Volume           (in**3):       5.9000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

The program will take the values for peak pressure, barrel length, propellant weights, and chamber volume to estimate a muzzle velocity. The results of the analysis will be displayed in tabulated form:

```
Interior Ballistics Results
    Gun Parameters

Barrel Length      (in):      64.00
Chamber Volume (in**3):       5.900
Bore Area      (in**2):      0.7849

    Projected Parameters
Projected Weight: 0.297 (lbm) 2084. (grains) 135.0 (grams)
Projected Diameter (in)       0.985

    Ballistic Parameters
Charge/mass Ratio            0.7528
Expansion Ratio              9.5139
Propellant Weight - 0.224(lbm) 1569.(grains) 101.65(grams)
Loading Density(lbm/in**3)        0.0380
Muzzle Velocity   (ft/sec)        4375.2
```

If the user selects to send the input menu to the line printer file, the output will also be sent to the line printer file. The program will then return to the point where the muzzle velocity input was displayed. Note that the muzzle velocity has not been changed by the Empirical Interior Ballistic program. If the user wants to use the value computed, it must be entered at this point.

Once the velocities have been established a summary of the stability results, together with a drawing of the flying portion of the projectile model, will be displayed. Additional output options are available at this point (Figure 12).

Option One will cause a return to the stability input menu.

Option Two will cause a return to the muzzle and aircraft velocity input menu.

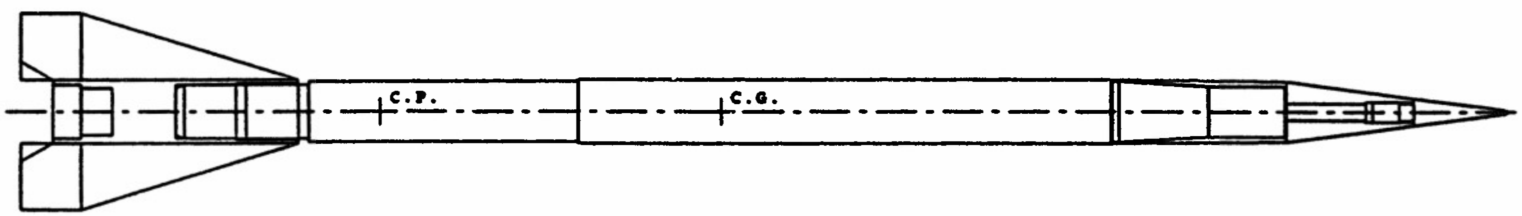
Option Three will display the menu of plots available for output. The menu available depends on the form of projectile being analyzed. For fin stabilized:

```
          Stability Plot Segment

vs Mach Number        vs Spin/Nut. Freq.
   1 CX                   11 W1
   2 CNa                  12 W2
   3 CPN                  13 L1
   4 Cma                  14 L2
   5 Cmq                  15 AF

   20 Return
:
```

Filename: I120M829

120MM M829 APDS-FS

Projectile Length = 613.969 (mm)
Sabot Length = 334.797 (mm)
Ogive Length = 91.618 (mm)
Band Length = 81.102 (mm)
Penetrator Length = 457.479 (mm)



Stability Results

Rifling Twist	0.0 (mm/rev)	0.0 (cal ibers/rev)
Muzzle Velocity	1670.00 (m/sec)	
Aircraft Velocity	0.00 (m/sec)	
Air Density	.001225 (gram/cm**3)	
Air Temperature	15.0 (Deg C)	
Center of Pressure from Nose	465.696 (mm)	17.579 (cal ibers)
Center of Gravity From Nose	325.514 (mm)	12.287 (cal ibers)
Dynamic Stability Factor	0.000	
Static Margin	140.181 (mm)	5.291 (cal ibers)

Figure 12. Stability Summary

For spin stabilized:

Stability Plot Segment

1 CX	**8 CPN**
2 CNa	**9 Gyro Stability Factor**
3 Cma	**10 Dynamic Stability Factor (SBAR)**
4 Cmq	**11 L1**
5 Clp	**12 L2**
6 Cnpa	

20 Return
21 Dynamic Stability Criteria
:

Figure 13 shows the normal force (CNa) curve found by this analysis. The Dynamic Stability Criteria plot (21) shows the projected stability/instability for each of the Mach numbers analyzed and where they fall relative to the stability curve (Figure 14). In this example we see that this projectile will be unstable at subsonic speeds.

Option Four will display the plots available for cross plotting. In stability, unlike the other PRODAS segments, cross plotting will plot the current analysis against data stored in previously cataloged analyses and not against analyses made during this session. If the user selects to enter stability without first entering model geometry, the program will branch to the stability cross plot module. The data available for cross plotting (both spin and fin stabilized) is:

1 - CX
2 - CNa
3 - Cma
4 - Cmq
5 - Clp
6 - Return

Figure 15 shows a cross plot of drag data for spin stabilized projectiles.

Option Five will return the program to the main PRODAS menu.

Option Six will cause the printed output that has been displayed on the screen to be written into a file for printing on a line printer.

Option Seven is available only if a laser printer is available that supports PLOT-10. This will cause a plot of this stability summary to be made.

If the user enters the stability option without entering a projectile, the program assumes that the user wishes to create cross plots from the cataloged data.

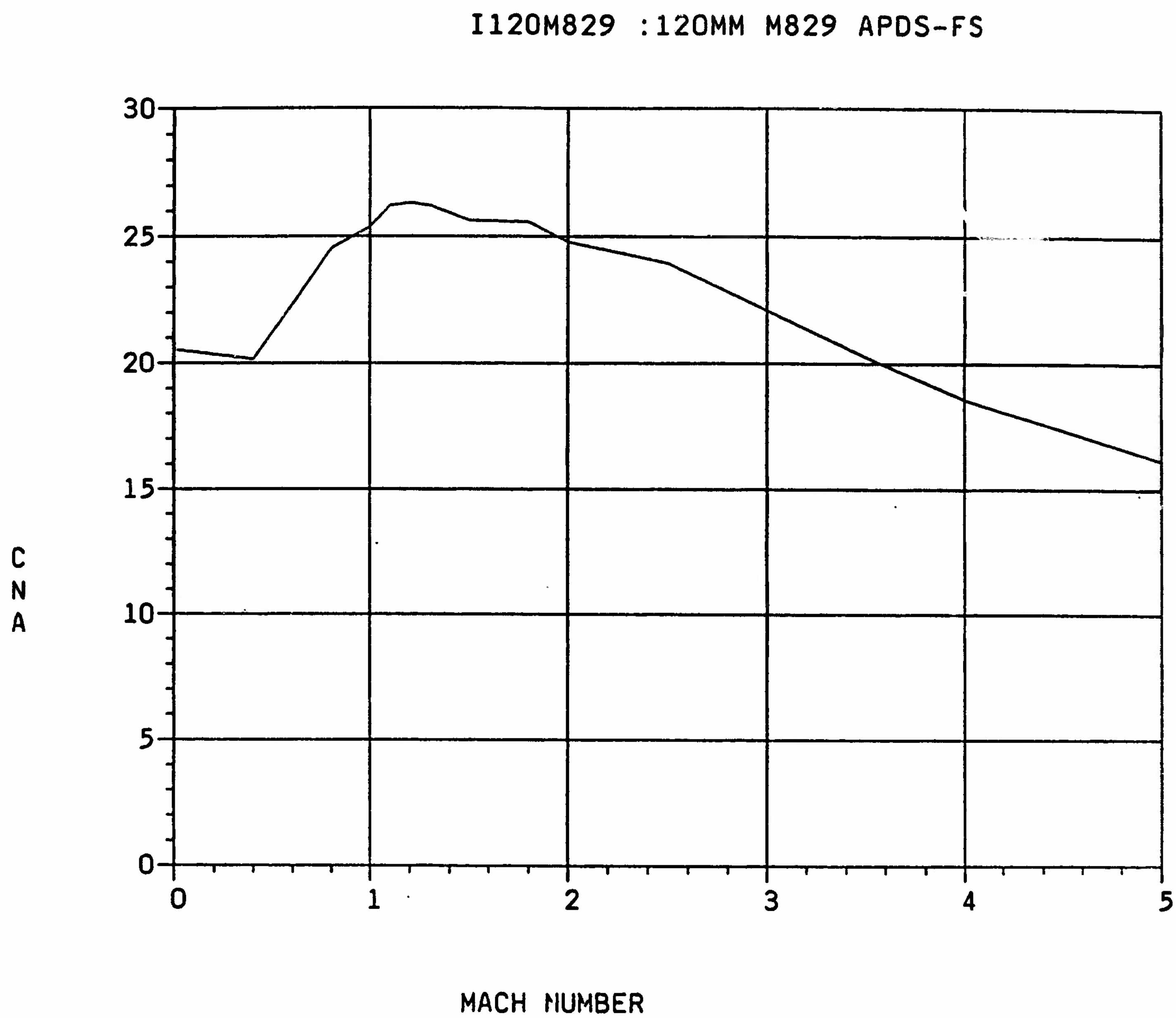


Figure 13. Stability Output Plot

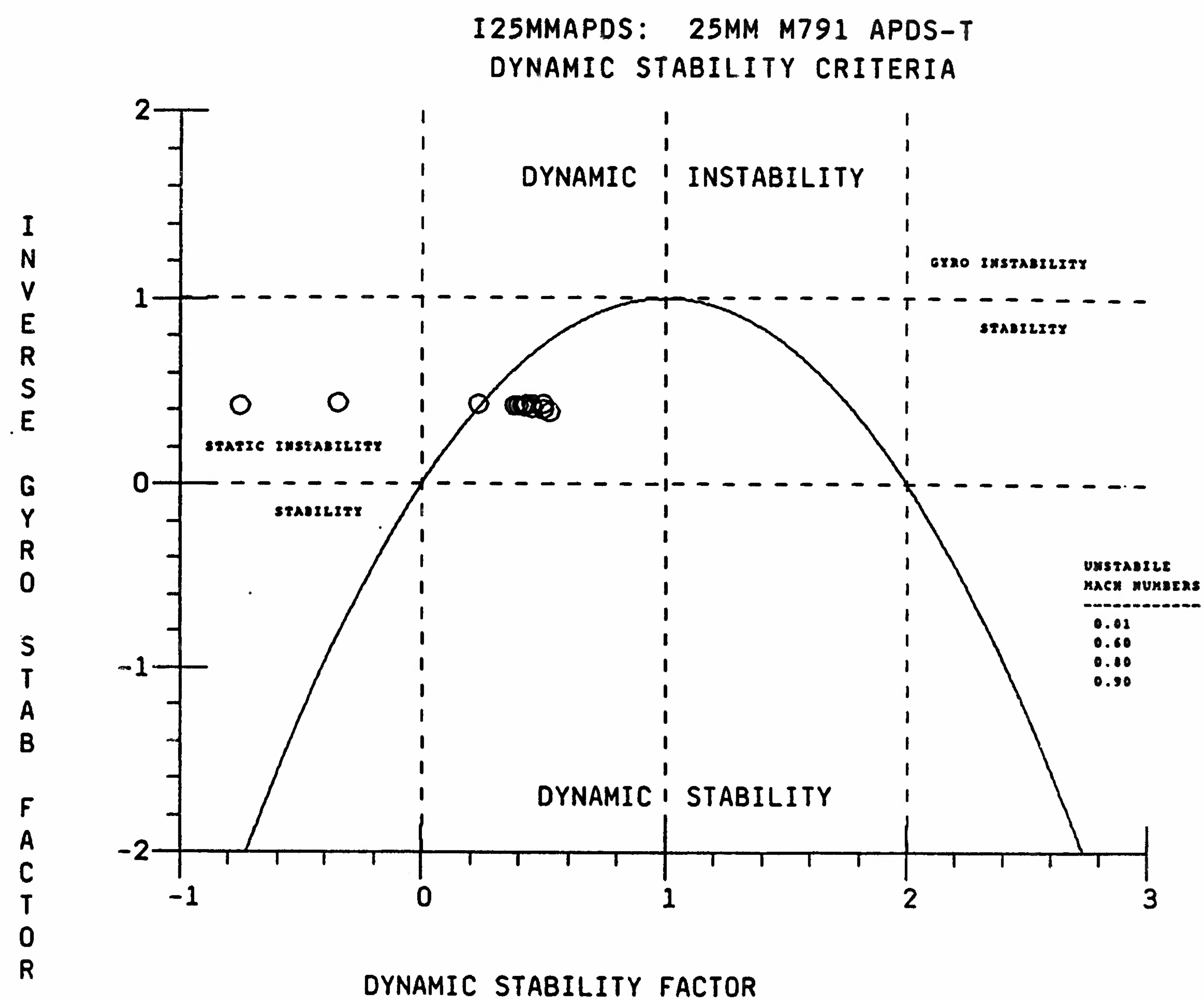


Figure 14. SPINNER Stability Criteria

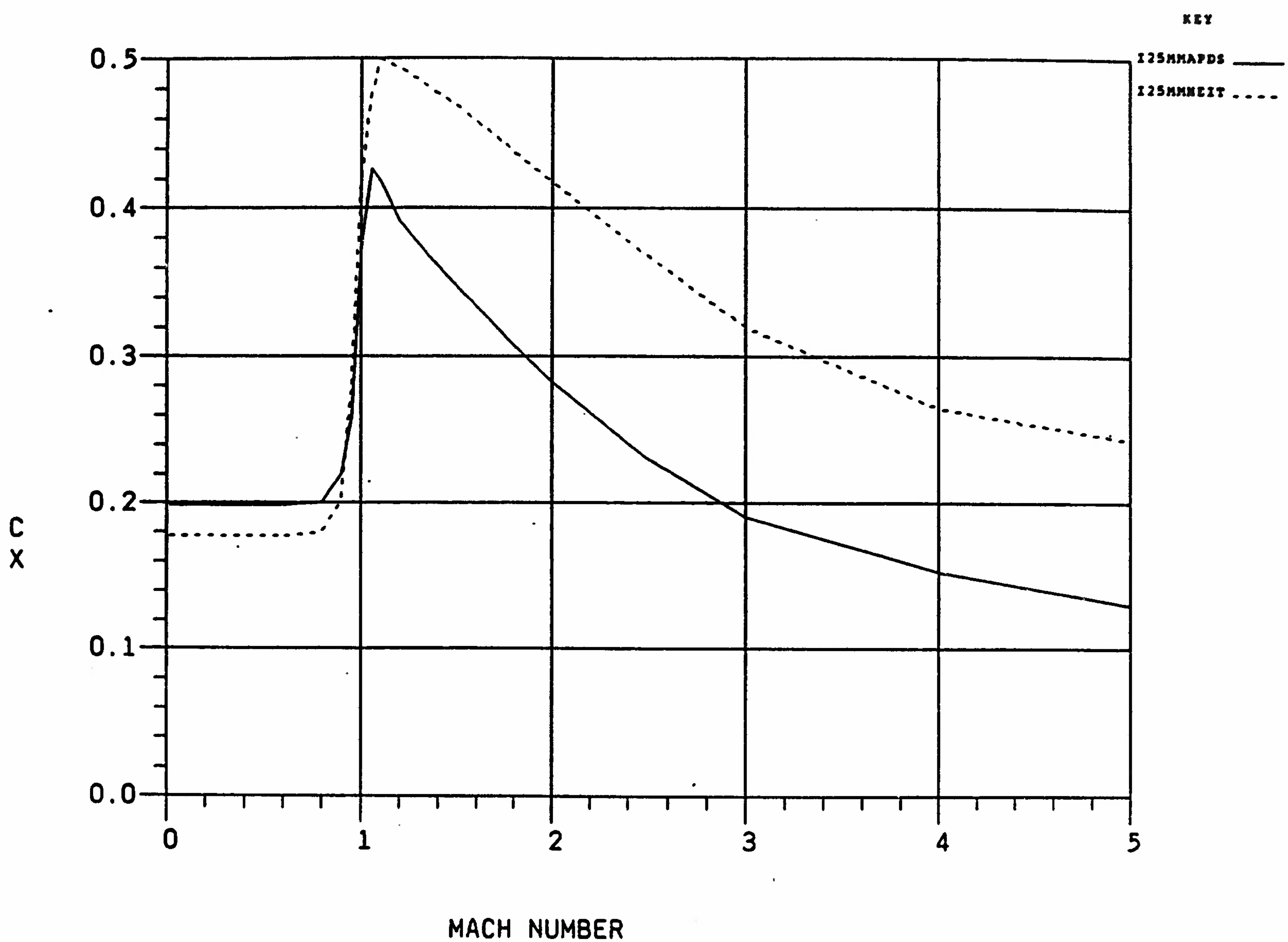


Figure 15. Stability Cross Plot

g. T - 2 / 6 Degree of Freedom Trajectory

This module performs either a 2 or 6 DOF trajectory analysis. If the module is selected without first defining a projectile model, the program will proceed to the cross plot segment.

Three input menus are needed to specify the basic trajectory physical and analysis parameters. The first menu is used to define the overall projectile configuration, which determines the additional input menus needed, and what additional output is desired:

```
Trajectory Analysis Options Selection
-------------------------------------

1 - Type of projectile                          : 2
    (1 - Fin stabilized  2 - Spin stabilized)
2 - Type of trajectory simulation               : 2
    (2 - Two DOF            6 - Six DOF)
3 - Perform FUMER analysis                      : 0
    (0 - No                 1 - Yes)
4 - Does the trajectory originate at an aircraft: 0
    (0 - No                 1 - Yes)
5 - Perform internal ball rotor simulation      : 0
    (0 - No                 1 - Yes)
6 - Enter number of barrels in gun              : 1
7 - Examine or modify the aerodynamics          : 0
    (0 - No                 1 - Yes)
8 - Generate cross plot file                    : 0
    (0 - No                 1 - Yes)
9 - Write a QUICK6 or MODTRAJ datafile          : 0
    (0 - No file    1 - QUICK6    2 - MODTRAJ)

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

Line one specifies the projectile stability configuration, fin or spin. The program will examine the projectile model for fin elements to initialize this parameter.

Line two specifies which equations of motion are to be used for the analysis, 2 or 6 DOF. By default the program will perform a 2 DOF analysis. For the 2 DOF analysis, aerodynamic jump, velocity jump, and yaw of repose effects are taken into account. Aerodynamic and velocity jump effects are the result of firing around an axis that does not match the direction of air flow, i.e., side firing from an aircraft. This causes an angle of attack for the projectile greater than it would normally have for no yaw motion. Yaw of repose is the resistance of a spin stabilized projectile's nose to following the ballistic trajectory, i.e. keeping a nose up orientation as the projectile comes over the apex of the arc in the trajectory.

If tracer burn or rocket effects are to be included, line three (fumer) should be flagged.

For a projectile launched from an aircraft, line four will cause the aircraft parameter menu to be displayed.

Line five will cause the ball rotor fuze input menu to be displayed. This enables the effect of a moving component in the fuze to be included in the equations of motion.

The number of barrels is specified in line six. A multiple barreled gun is assumed to be a gatling gun.

The Stability analysis segment of PRODAS computes aerodynamic coefficients. Line seven allows the user to display and modify these parameters.

Line eight allows the user to flag the program to store trajectory data for the creation of multiple analysis plots. This trajectory data will also be stored for use by other analysis modules within PRODAS (i.e., Target Penetration).

Line nine allows the user to specify that the trajectory input data is to be stored for use by either the QUICK6 or MODTRAJ programs. In either of these cases, trajectory analysis will not be performed. QUICK6 is a batch 6 DOF analysis program. MODTRAJ is a program for simulating a ballistic range. The program creates data points to simulate the camera X-Y-Z-theta-psi data with noise. (See Section II.)

The menus flagged by the above options will be explained in the following pages.

The second and third menus specify the projectile physical properties and basic trajectory analysis parameters:

Trajectory Analysis Conditions (Page 1)

1 - Projectile Diameter	(in):	0.531
2 - Axial Inertia	(lbm-in**2):	0.007581
3 - Transverse Inertia	(lbm-in**2):	0.058568
4 - Center of Gravity	(calibers from nose):	3.560
5 - Drag Form Factor	:	1.000
6 - Fin Cant Angle	(deg):	0.0000
7 - Number of Fins	:	0.
8 - Projectile Weight	(lbm):	0.2305
9 - Switch time from 6 DOF to 2 DOF	:	999.000
10 - Linear theory stability analysis (0 - no 1 - yes)	:	0
11 - Aerodynamic jump included (0 - no 1 - yes)	:	0
12 - Limiting total angle of attack for which nonlinear coef's are considered	(deg):	10.000
13 - Gun Elevation Angle (0.0 if aircraft originated)	(deg +=up):	1.000
14 - Gun Azimuth Angle	(deg +=left):	0.000

Trajectory Analysis Conditions (Page 1) - (Continued)

```
15 - Missile angle of attack-THETAM            :          0.00
     (deg +=nose down)
16 - Missile angle of sideslip-PSIM            :          0.00
     (deg +=nose left)

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "CALC" to calculate
Key in "PRINT" for a Line printer output
```

Lines one through nine specify the physical parameters. These values are calculated in the Physical Properties segment.

Line ten allows for calculation of the linear theory gyroscopic and dynamic stability factors.

Line eleven causes the aerodynamic jump effects to be included.

Line twelve specifies the upper limit of angle of attack for non-linear coefficients. By default this value is 10 degrees.

Lines thirteen and fourteen define the gun orientation.

Lines fifteen and sixteen define the angular orientation of the projectile at muzzle exit. These parameters do not have an effect in a 2 DOF analysis. The "CALC" option will run the Muzzle Exit segment of PRODAS to assist in the selection of initial pitch and yaw values. After running Muzzle Exit, the program will return to this input menu:

Trajectory Analysis Conditions (Page 2)

```
 1 - Pitch Angular Velocity                  :         0.00
     (rad/sec, +=nose down)
 2 - Yaw Angular Velocity                    :         0.00
     (rad/sec, +=nose left)
 3 - Initial Axial Spin                      :    13947.201
     (rad/sec, +=right hand twist)
 4 - Atmos. Sea Level Temp.         (Deg F):         59.00
 5 - Wind Range           (fps, +=down range):       0.0000
 6 - Cross Wind                 (fps, +=left):       0.0000
 7 - Vertical Wind                (fps, +=up):       0.0000
 8 - Muzzle Velocity                (ft/sec):    4350.0000
 9 - Initial Altitude                   (ft):       0.0000
10 - Initial Horizontal Range           (ft):      64.4461
11 - Initial Cross Range      (ft, +=left):       0.0000
12 - Initial Time                      (sec):       0.0000
13 - Integration Time Increment        (sec):    0.0200000
     if 0.0 default = nutation freq./20.
14 - Maximum Time                      (sec):      70.0000
15 - Maximum Slant Range                (ft):     10000.00
```

Output Increment	Time or Slant Range	
16 - Time	(sec):	0.1000
17 - Slant Range	(ft):	0.00

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "CALC" to calculate
Key in "PRINT" for a Line printer output

Lines one and two define the angular velocity of the projectile at the muzzle exit. These parameters do not have an effect in a 2 DOF analysis. The "CALC" option will run the Muzzle Exit segment of PRODAS to assist in the selection of initial pitch and yaw rate values. After running Muzzle Exit, the program will return to this input menu.

Line three defines the projectile spin. A value of 60 rad/sec is assigned for fin stabilized projectiles. The program cannot handle a projectile with a spin of zero. The spin is computed from the rifling twist as defined in the stability analysis and the muzzle velocity. If the muzzle velocity is changed, a new spin rate will be computed.

Lines four through twelve define the initial atmospheric conditions and gun projectile exit conditions.

Line thirteen is the integration time step. For a 2 DOF analysis the program will default to 0.02 second. For a 6 DOF analysis the program will use the value stored in the projectile data file. For an initial analysis a value of zero should be entered. This will cause the program to compute a value equal to 1/20th the nutation frequency. This will cause an automatic redisplay of the menu. The time step may now be modified to a round value if desired.

The trajectory analysis will run until one of three conditions is reached; the projectile strikes ground ($z<=0$), the maximum time is reached (line 14), or the maximum slant range, the distance from the muzzle to the projectile in 3D space, is reached (line 15). If the projectile strikes the ground, the program will interpolate the output data back to $z=0$.

Trajectory output may be created by one of two methods, even increments of time or slant range. The program will allow a maximum of 500 output points to be calculated. Caution should be taken in using slant range output with high angles of attack. As a projectile comes over the top of the trajectory it is possible for the slant range to start decreasing.

If the user selects to examine/modify the aerodynamic coefficients, Table 8 will be displayed. The look of this menu will depend on the type of projectile and terminal being used. For a fin stabilized projectile there are a total of three menus. A spin stabilized projectile has two. In the small screen mode these menus each take two screens to display. To make

TABLE 8. AERODYNAMIC COEFFICIENTS

Aerodynamic Coefficients (Page 1)

Row	Column 1 Mach No.	Column 2 CX0	Column 3 CX2	Column 4 Cnȧ	Column 5 Cna3	Column 6 CYpa	Column 7 Cnpa7	Column 8 Clp	Column 9 Cld
1	0.0100	0.1980	2.4365	2.2427	0.0000	-0.8453	0.0000	-0.0316	0.0000
2	0.6000	0.1980	2.4365	2.2427	0.0000	-0.8453	0.0000	-0.0315	0.0000
3	0.8000	0.2004	2.8771	2.2627	0.0000	-0.8453	0.0000	-0.0299	0.0000
4	0.9000	0.2200	3.3081	2.2925	0.0000	-0.9509	0.0000	-0.0284	0.0000
.									
.									
.									
14	2.5000	0.2300	2.9058	2.8740	0.0000	-0.8453	0.0000	-0.0213	0.0000
15	3.0000	0.1900	2.4653	2.7943	0.0000	-0.8453	0.0000	-0.0202	0.0000
16	4.0000	0.1520	2.0452	2.6943	0.0000	-0.8453	0.0000	-0.0195	0.0000
17	5.0000	0.1300	1.6251	2.5943	0.0000	-0.8453	0.0000	-0.0192	0.0000

Key in column number to modify a column
Enter "S" to populate column with last value entered
Key in "DONE" to continue
Key in "LIST" to relist"
Key in "PRINT" for a Line printer output

Aerodynamic Coefficients (Page 2)

Row	Column 1 Mach No.	Column 2 Cma	Column 3 Cma3	Column 4 Cma5	Column 5 Cnpa	Column 6 Cnpa3	Column 7 Cnpa5	Column 8 Cmq	Column 9 Cmq2
1	0.0100	3.2402	0.0000	0.0000	-0.8769	17.3960	-136.4598	-3.1916	0.0000
2	0.6000	3.2626	0.0000	0.0000	-0.8769	17.3960	-136.4598	-3.1916	0.0000
3	0.8000	3.3370	0.0000	0.0000	-0.7078	15.7479	-119.9791	-3.1916	0.0000
4	0.9000	3.3622	0.0000	0.0000	-0.4159	11.3185	-75.6853	-6.4809	0.0000
.									
.									
.									
14	2.5000	3.5789	0.0000	0.0000	0.1713	0.2555	34.9451	-26.2260	0.0000
15	3.0000	3.5858	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000
16	4.0000	3.5384	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000
17	5.0000	3.4849	0.0000	0.0000	0.1797	0.0907	36.5930	-26.2260	0.0000

Key in column number to modify a column
Enter "S" to populate column with last value entered
Key in "DONE" to continue
Key in "LIST" to relist"
Key in "PRINT" for a Line printer output

modifications to these tables first enter the column number. Next, enter line numbers and new values for each Mach number to be modified. Enter a <cr> with no line number when modifying a column. If an "S" is entered after the <cr>, all values in the column with Mach numbers higher than the last one modified will be given the values last entered.

If a fumer analysis was selected on menu number 1, the following Fumer Input Menu will be displayed:

```
Trajectory - FUMER Analysis - Input
-----------------------------------

1 - Axial Inertia at Burnout      (lbm-in**2):     0.007581
2 - Transverse Inertia at Burnout (lbm-in**2):     0.058568
3 - Projectile Weight at Burnout        (lbm):     0.230478
4 - Center of Gravity    (calibers from nose):     3.560222
5 - Multiple Nozzle Cant Angle          (deg):     0.000000
6 - Multiple Nozzle Exit Radius          (in):     0.000000
    (from projectile centerline)
7 - Burn Start Time                     (sec):     0.000000
8 - Burn Stop Time                      (sec):     2.400000
9 - Do you wish to input the drag vs time   :             2
    profile or the drag vs Mach no. curve?
(0:Continue 1:Drag & Thrust vs Time 2:Drag vs Mach No.)
Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

On this menu the physical properties of the projectile after fumer burn out are defined. The Physical Properties segment computes properties with and without the tracer elements. Properties are assumed to vary linearly during the time of the tracer/fumer burn. It is not necessary that tracer elements exist to perform a fumer analysis. If more than one nozzle exists, the radius of the nozzle cluster and cant angle of the nozzles may be specified. The program assumes the nozzles are arranged in a circular pattern. The values entered for thrust are the thrust along the nozzle orientation. The thrust along the projectile axis will be the thrust times the cosine of the cant angle. A rotational force of thrust times the sine of the cant angle is also computed for each nozzle.

Line nine allows for the specification of projectile thrust and/or drag reduction during the projectile burn. An entry of one or two will cause additional input menu(s) to be displayed. An entry of one will display:

```
Trajectory - FUMER Analysis (Drag & Thrust vs Time) - Input
-----------------------------------------------------------

Decrease in Drag Coef. as a Function of Time
Entry #     Burn Time     Delta CX      Thrust
               sec                       lbf
Key in "DONE" to continue
Key in "LIST" to relist
Key in "PRINT" for a Line printer output
Key in values separated by commas to modify
```

Up to 20 lines of input may be specified here. Each line must contain a time, delta drag, and thrust entry. Zero may be entered for thrust and drag. Time must be entered in ascending order. The drag reduction entered here is magnitude reduction (negative for increase). During the analysis, the program will perform a linear interpolation from this table.

Option Two in line nine allows for the specification of a reduced drag versus Mach number. A table of drag versus Mach number with and without fumer burn will be displayed. If stability analysis has been run, and this is a spin stabilized projectile, a base drag from McDrag will be displayed. Otherwise the base drag is specified the same as the total drag. The base drag is displayed only for reference purposes. The analysis only uses the total drag:

Trajectory - FUMER Analysis (Drag vs Mach Number) - Input

	No Fumer		During Burn	
Mach Number	**Total Drag**	**Base Drag**	**Total Drag**	**Base Drag**
0.0100	0.1980	0.1384	1: 0.1822	18: 0.1384
0.6000	0.1980	0.1411	2: 0.1822	19: 0.1411
0.8000	0.2004	0.1477	3: 0.1844	20: 0.1477
0.9000	0.2200	0.1645	4: 0.2024	21: 0.1645
0.9500	0.2590	0.1776	5: 0.2383	22: 0.1776
1.0000	0.3710	0.2518	6: 0.3413	23: 0.2518
1.0500	0.4270	0.2122	7: 0.3928	24: 0.2122
1.1000	0.4180	0.2169	8: 0.3846	25: 0.2169
1.2000	0.3920	0.2108	9: 0.3606	26: 0.2108
1.3500	0.3670	0.2015	10: 0.3376	27: 0.2015
1.5000	0.3460	0.1915	11: 0.3183	28: 0.1915
1.7500	0.3130	0.1733	12: 0.2880	29: 0.1733
2.0000	0.2820	0.1543	13: 0.2594	30: 0.1543
2.5000	0.2300	0.1200	14: 0.2116	31: 0.1200
3.0000	0.1900	0.0927	15: 0.1748	32: 0.0927
4.0000	0.1520	0.0631	16: 0.1398	33: 0.0631
5.0000	0.1300	0.0454	17: 0.1196	34: 0.0454

35 Total burn drag as % of total drag
36 Base burn drag as % of base drag

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Note that modifications will be reflected against each other
Key in "PRINT" for a Line printer output

This table includes four options for modifying the drag. The total drag or base drag during burn may be changed directly. This is done by modifying lines one through thirty-four.

For any change to total drag, the same magnitude change to base drag at that Mach number will be computed. Conversely, changes in base drag are reflected on the total drag. Options Thirty Five and Thirty Six allow for across the board changes by a specified percentage. With Option Thirty Five, a fractional value is specified by which the total drag for all Mach numbers will be multiplied. The magnitude change will then be subtracted from the base drag. Option Thirty Six performs the same operation on the base drag. The fractional value used is stored in the projectile model file and will be displayed when this operation is selected. It is displayed only for reference purposes so it must be reentered.

If Options Thirty Five or Thirty Six are selected the table will be redisplayed in the modified form automatically.

If desired, both the drag versus time and drag versus Mach number tables may be used. For the case of a rocket it will be necessary to use the drag versus time menu to specify the projectile thrust profile. Depending on how the drag reduction data is specified it may be necessary to use either or both menus to define the drag reduction.

If an aircraft-originated trajectory was specified in menu number one, the following menu will be displayed for specification of the aircraft parameters:

Trajectory - Aircraft Originated - Input

Aircraft Inputs

1 - Aircraft Velocity	**(ft / sec):**	**0.000**
2 - Aircraft Dive Angle	**(deg., +=down):**	**0.000**
3 - Aircraft Dive Azimuth	**(deg., +=nose left):**	**0.000**
4 - Aircraft Pitch Angle	**(deg., +=nose down):**	**0.000**
5 - Aircraft Yaw Angle	**(deg., +=nose left):**	**0.000**
6 - Gun Elevation WRT Aircraft	**(deg., +=up):**	**0.000**
7 - Gun Azimuth WRT Aircraft	**(deg., +=left):**	**0.000**

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output

For an aircraft-originated trajectory, the elevation angle used for the analysis will be the dive angle from this menu. Any other value entered will be ignored.

If a ball rotor simulation was selected on menu number one, the following menu will be displayed:

Trajectory - Ball Rotor Simulation - Input

```
1 - Ball Weight                (grams):   0.0000
2 - Ball CG from Projectile CG (in):      0.0000
3 - Ball Clearance             (in):      0.0000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

If more than one barrel was specified in menu number one, the Multiple Barrel Input menu will be displayed:

Trajectory - Multiple Barrel Gun - Input

Multibarrel Gun Inputs

```
1 - Gun Half-cone Angle              (deg):        0.000
2 - Muzzle Radius                     (in):        0.000
3 - Sear-off Position        (deg, +=cclu):        0.000
    from bottom vertical looking downrange
4 - Rate of Fire                     (SPM):        0.000
5 - Action Time                     (msec):        0.000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "PRINT" for a Line printer output
```

These inputs define the rotational motion of a Gatling gun barrel cluster. This data will determine the angular forces applied to the projectile on exit from the barrel.

This completes the data input for trajectory analysis. The program will perform the analysis and integrate the equations of motion. A fourth order Runge-Kutta integration is used. The results of the last integration step will be printed out followed by the output options:

Terminal Parameters

```
Velocity =   690.244 (ft/sec)
X-dist   = 33119.441 (ft)
Y-dist   =  -129.914 (ft)
Z-dist   =     0.000 (ft)
Time     =  24.48492 (sec)
```

Once the terminal parameters have been displayed, the output option menu will appear:

6 DOF Trajectory Segment Output

Plots

Time of Flight(sec)		Slant Range(ft)
1	X (ft)	21
2	Y (ft)	22
3	Z (ft)	23
4	Slant Range (ft)	24
5	Velocity (ft/sec)	25
6	Mach Number	26
7	Spin Rate (rad/sec)	27
8	Total Yaw (deg)	28
9	Drop	29
10	Drift	30
11	Gyro. Stability Factor	31
12	Pitch [THETA]-M (deg)	32
13	Yaw [PSI]-M (deg)	33
14	Angular Accel (rad/sec2)	34
15	Angular Rate (rad/sec)	35
16	Dynamic Stability Factor	36
17	Kinetic Energy	37

38 Y vs X
39 Z vs X
40 Theta vs Psi

50 Return to Input
51 Cross Plots
52 Return to Main Menu

54 Tic mark switch (on)

Tables

61 Complete Output
62 T vs X,Y,Z,XBAR,V,Spin,Drop,Deflection
63 T vs X,Y,Z,Phi,Theta,Psi,Alpha
64 T vs X,Y,Z for Projectile WRT Barrel C.L. Gun C.L., Aircraft C.L.
65 T vs X,Y,Z,V,RE

Plots are against either time-of-flight or slant range. Tables are computed for time-of-flight and will be sent to the designated output printer.

Gyroscopic and dynamic stability plots are only available if the linear theory option was selected (input menu number two).

Pitch and yaw data is only available if a 6 DOF analysis was run.

Option Fifty One will send the program to the cross plot menu. The names and descriptions of the trajectories available for plotting will be listed. Up to 10 trajectories may be selected from this list for plotting together. Approximately 500 points will be plotted together. If each curve contains 500 points and three curves are to be plotted together, then every third point will be plotted. The more curves that are plotted together, the fewer points on each curve.

Option Fifty Four will toggle the tick mark flag. The option specifies which way the toggle will go. For a slant range plot the tick marks will show each second of time of flight. For a slant range plot, the tick marks will show each 1000 feet/meters of slant range.

6 DOF Trajectory Cross Plot Segment

Time of Flight		Slant Range(ft)
1	X (ft)	21
2	Y (ft)	22
3	Z (ft)	23
4	Slant Range (ft)	24
5	Velocity (fps)	25
6	Mach No.	26
7	Spin Rate (rad/sec)	27
8	Total Yaw (deg)	28
9	Drop (mrad)	29
10	Drift (mrad)	30
11	Gyroscopic Stability Factor	31
12	Theta-M (deg)	32
13	Psi-M (deg)	33
14	Dynamic Stability Factor	34
15	Kinetic Energy	35

38 Y vs X
39 Z vs X

50 Return to Input
52 Return to Main Menu
53 Return to Plot Menu

54 Tic mark switch (on)

Figure 16 shows a cross plot of Z vs X for elevation angle variation.

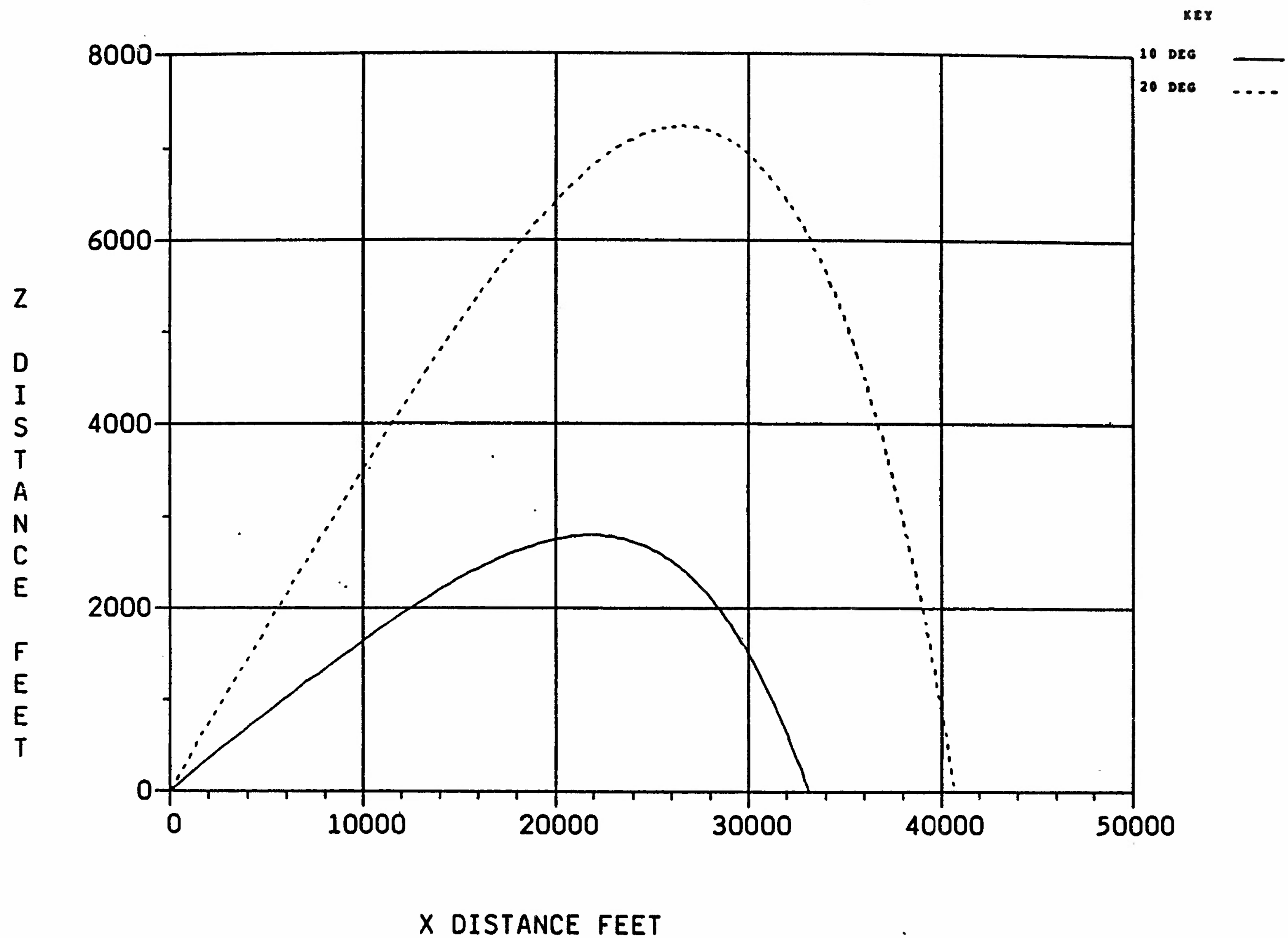


Figure 16. Cross Plotted Trajectory

SECTION VI

LINEAR THEORY

1. GENERAL

Within one executable program both the data input and analysis are performed. Once data has been input it may be stored for future reference. The following options menu will be displayed for data input/analysis:

Enter the number of the desired option

1 - Edit Input Data
2 - Run Analysis
3 - Store Master File Data
4 - Exit Linear Theory Program

:

The program will not allow for analysis (Option Two) until data has been returned from the editing module (Option One). Data may be stored (Option Three) before or after the running of an analysis. It is advised that data be stored on exiting the edit module. Storing input at this time will prevent data being lost if a hard crash occurs during the analysis. If the results of the analysis are acceptable, it is advised that the data be stored again. By doing this, the parameters found from the analysis will be the initial estimates for any future reduction of this shot.

2. LINEAR THEORY INPUT

Upon entering the data Edit/Input module, the following menu of options will be displayed:

1 - Initialize new data set
2 - Retrieve cataloged data set

3 - Shot number and description
4 - Linear Theory analysis Flags
5 - Projectile physical properties
6 - Analysis reference data
7 - Initial aerodynamic coefficient estimates
8 - Initial aerodynamic parameters estimates
9 - Aerodynamic fit flags
10 - Atmospheric parameters

11 - Edit current Tunnel XYZ data
12 - Use new data set from Tunnel XYZ file
13 - Delete current Tunnel XYZ data

14 - Done

Each of the above options will cause a different menu of parameters to be presented for editing. A common procedure for editing has been established. The line number and new value are entered, with one change per line. A "LIST" option will redisplay the data with the changes. "DONE" will terminate the edit session and return to the above menu. "R" will cause the program to step through each entry in the edit menu. The line numbers within the menu will be incremented automatically.

The first step in an editing session is either to retrieve an existing data set or to initialize a new data set. Edit Option One is used to initialize a new data set. Under this option, the program will automatically step through Options Three through Ten and Option Twelve.

To retrieve data stored during a previous data reduction session use Edit Option Two. If the user chooses to retrieve existing data, a question will appear requesting the shot number. A list of available shots may be displayed at this time:

Key in 10 digit projectile title (or LIST): LIST

Enter the shot group number to list: -1

Linear Theory Projectile Titles
Previous Reduction

Shot Group	Shot Number	Date	Time	Description
9	BS87040819	1-SEP-87	13:04:00	40 MM HEDP TUBULAR REREAD
9	BS87040613	1-SEP-87	13:04:00	40 MM HEDP TUBULAR REREAD
9	BS87040209	1-SEP-87	11:57:20	40 MM HEDP TUBULAR REREAD
8	BS87080617	24-AUG-87	15:24:13	20 MM BOOMED/CASED
8	BS87080618	24-AUG-87	15:24:13	20 MM BOOMED/CASED
0	BS87032490	26-JUN-87	10:37:12	40 MM HEDP TUBULAR
0	BS87032797	26-JUN-87	10:37:12	40 MM HEDP TUBULAR
0	BS87042434	15-JUN-87	10:49:38	20 MM BOOMED/CASED
9	BS87042333	15-JUN-87	10:49:38	20 MM BOOMED/CASED

Key in 10 digit projectile title (or LIST): BS87040716

Note that in the above table a negative shot group number was entered. A positive group number will cause only that shot group to be displayed. A negative group number will cause all shot groups to be displayed. Within this table are the date and time that the shot was previously cataloged.

Edit Option Three will allow the user to specify a new shot number and description.

Edit Option Four contains the analysis option flags:

Linear Theory Analysis Flags

```
  1 - Starting point to fit                               [LN]:  1
  2 - Length of first section to be fit                   [NA]: 25
  3 - Incremental section increment                       [ND]:  0
  4 - Summing section increment                           [NB]:  2
  5 - Frequency guess                                  [NAUTO]:  0
      0: Do not use Cma     1: Use Cma
  6 - Roll Flag                                        [NROLL]:  0
      0: Roll data not available (or do not use)
      1: Roll data available (automatic unwind)
      2: Use roll data as is (already unwound)
      3: Unwind roll data
  7 - Automatic guess routine flag                       [NSG]:  0
      0: Do not use          1: Use
  8 - Spin Flag                                        [NSPIN]:  0
      0: Spin stabilized (fixed plane)
      1: Fin stabilized (fixed plane)
      2: Fin stabilized (body fixed)
      3: Fin stabilized Cma <> -CNB (body fixed)
  9 - Sections Flag                                    [NSECT]:  3
      0: Use LN, NA, ND, NB
      1: Use automatic sections (Output sectional fits)
      2: Use automatic sections (Output 1 to NT)
      3: Help
 10 - Shot Group Number                                 [IGRP]:  0

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "R" to step through input
```

Within this table, LN,NA,ND,NB are used to define the section of range stations to be used in fitting the data and how the data will be incremented.

NROLL is used by the program to flag the routines used to analyze the roll data.

If NSG is set on (set to 1), the program will automatically select the parameters to fit.

NSPIN specifies the type of projectile, fin or spin stabilized, and the coordinate system, fixed plane or body fixed.

If NSECT is set to three, the HELP routines will be called. These routines give the user a chance to control fit curve fitting interactively to help get things started. During the HELP phase only yaw motion is being analyzed. Plotted and tabulated data is available for examination. (See next section on Linear Theory Help.)

The shot group number is initially set by the TDBIAS program and may be modified here if desired.

Edit Option Five contains the physical properties of the projectile to be analyzed:

Projectile Properties

```
1 - Projectile diameter          [D]           (in):      1.558
2 - Axial moment of inertia     [IX] (slug-ft-in):      0.0005250
3 - Y axis moment of inertia    [IY] (slug-ft-in):      0.0010540
4 - Z axis moment of inertia    [IZ] (slug-ft-in):      0.0010540
5 - Product of inertia         [IXY] (slug-ft-in):      0.0000000
6 - Projectile weight          [WGT]         (gram):    244.77800
7 - Center of gravity          [XCG]   (from nose):      0.612
8 - Projectile length           [XL]           (in):      3.084
```

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "R" to step through input

Edit Option Six contains the analysis reference parameters:

Analysis Reference Parameters

```
1 - Initial roll rate          [CA]             (deg/ft):   93.00000
2 - Roll pin orientation    [RBAIS]                (deg):    0.00000
3 - Reference mach number    [MREF]                     :    0.60000
4 - Reference diameter       [DIAR]                 (in):    1.55764
5 - Reference CG location    [XCGR]          (from nose):    0.61200
6 - Reference length          [XLR]                 (in):    3.08440
7 - Number of fins           [XFIN]   (symmetry planes):           1
8 - Roll acceleration         [PH2]         (deg/ft**2): 0.0000E+00
```

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "R" to step through input

Edit Option Seven allows for modification of the aerodynamic coefficient estimates:

Estimates of Aerodynamic Coefficients

1 - CNa	:	2.00000
2 - Cma	:	1.40000
3 - Clp	:	-0.02600
4 - Cld	:	0.00000
5 - CX Mach	:	0.00000
6 - CXa2	:	2.30000
7 - Gun Barrel Twist (cal/rev)	:	29.71000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "R" to step through input

Within linear theory only the gun barrel twist is used. The twist is used to determine the initial roll rate of the projectile. The other coefficients are just passed through the data file for initial estimates by the 6 DOF program.

Edit Option Eight allows for modification of the initial aerodynamic parameter estimates used by linear theory. The values of these parameters will change during the linear theory reduction. When a good fit is achieved the projectile file should be stored. This will cause the final (fit) values of the estimates to be retained as a future starting point:

Initial Aerodynamic Parameter Estimates

1 - Nutation vector	[K1]	(deg):	0.17710
2 - Precession vector	[K2]	(deg):	0.09820
3 - Nutation damping exponent	[L1]	(1/ft):	0.00070
4 - Precession damping exponent	[L2]	(1/ft):	0.00700
5 - Nutation vector orientation	[P1]	(deg):	299.06381
6 - Precession vector orientation	[P2]	(deg):	273.14471
7 - Nutation frequency	[W1]	(1/ft):	56.48310
8 - Precession frequency	[W2]	(1/ft):	23.84210
9 - Nutation freq. change	[WD1]	(deg/ft**2):	0.00600
10 - Precession freq. change	[WD2]	(deg/ft**2):	0.00340
11 - Trim vector	[K3]	(deg):	0.00000
12 - Trim vector orientation	[P3]	(deg):	0.00000

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue
Key in "R" to step through input

Edit Option Nine allows for modification of the parameter fit flags. The flags that are set determine which estimates may be modified by the program during the data fitting:

```
             Aerodynamic Modification Fit Flags
             ----------------------------------

              1 - Nutation vector                 [K1] : 1
              2 - Precession vector               [K2] : 1
              3 - Nutation damping exponent       [L1] : 0
              4 - Precession damping exponent     [L2] : 1
              5 - Nutation vector orientation     [P1] : 1
              6 - Precession vector orientation   [P2] : 1
              7 - Nutation frequency              [W1] : 1
              8 - Precession frequency            [W2] : 1
              9 - Nutation freq. change          [WD1] : 0
             10 - Precession freq. change        [WD2] : 0
             11 - Trim vector                     [K3] : 0
             12 - Trim vector orientation         [P3] : 0
                  (0 - do not fit  :  1 - fit)
             13 - Restart flag                   [RES] : 0
                  (0 - Restart :  1 - No restart)


           Key in item number "," new value
           Key in "LIST" to relist "DONE" to continue
           Key in "R" to step through input
```

If the HELP option is to be run, these flags may be changed within that module.

Edit Option Ten allows for modification of the atmospheric parameters. Either relative humidity or air density may be specified. If either value is changed, the other will be computed and displayed:

```
             Atmospheric Conditions
             ----------------------

            1 - Air temperature      (Deg C):     19.600
            2 - Atmospheric pressure (mbar):    1026.200
            3 - Relative humidity           :      0.460
                       or
            4 - Air density     (slug/ft**3):     0.002361

           Key in item number "," new value
           Key in "LIST" to relist "DONE" to continue
```

Edit Option Eleven allows the user to modify time and roll data for any of the stations along the range. A table of the time and roll data for each range station along with the station distances will be displayed. Station distances may not be changed, they are only displayed for reference purposes. Entering a negative time will remove a station from the analysis:

Tunnel XYZ data for editing

Enter negative time to remove a station

Station Distance (feet)		Time (sec)		Roll (deg)	Station Distance (feet)		Time (sec)		Roll (deg)
11.9377	(1)	0.5584267	(14)	-99.	242.0256	(27)	0.7894410	(39)	-99.
17.1983	(2)	0.5634965	(15)	-99.	252.0643	(28)	0.7999383	(40)	-99.
27.1724	(3)	0.5731447	(16)	-99.	271.9348	(29)	0.8207810	(41)	-99.
47.2351	(4)	0.5925861	(17)	-99.	276.9530	(30)	0.8260718	(42)	-99.
57.1083	(5)	0.6022863	(18)	-99.	291.9944	(31)	0.8419708	(43)	-99.
67.0824	(6)	0.6120735	(19)	-99.	306.9884	(32)	0.8578804	(44)	-99.
72.1105	(7)	0.6170182	(20)	-99.	322.0588	(33)	0.8739316	(45)	-99.
76.9907	(8)	0.6218238	(21)	-99.	352.1425	(34)	0.9062108	(46)	-99.
151.9478	(9)	0.6967998	(22)	-99.	382.1923	(35)	0.9387400	(47)	-99.
181.9187	(10)	0.7273291	(23)	-99.	397.1584	(36)	0.9550332	(48)	-99.
186.9524	(11)	0.7324781	(24)	-99.	412.1839	(37)	0.9714601	(49)	-99.
212.0999	(12)	0.7583820	(25)	-99.	442.1961	(38)	1.0044963	(50)	-99.
222.1359	(13)	0.7687663	(26)	-99.					

Key in item number "," new value
Key in "LIST" to relist "DONE" to continue

If a station has been removed a -99 will be displayed for the roll angle.

Edit Option Twelve allows for the replacement of the Tunnel XYZ data set with the data for another shot number. The projectile name and description will be replaced as well, with that of the new Tunnel XYZ data set. All other data will remain the same as it was.

Edit Option Thirteen removes all Tunnel XYZ data but all other data remains.

3. LINEAR THEORY HELP

If the Linear Theory HELP option is selected in the Linear Theory Input (setting flag number nine to three in Edit Option Four), the program will branch into the HELP mode and remain there until directed otherwise. This

module performs a reduction on the yaw data and helps to refine the initial estimates before running the full linear theory reduction. The HELP input menu is:

```
BS87040716 40mm HEDP Tubular
28-SEP-87   16:18:26

 Station Options
 ---------------------------------------------------------------
 1 - Starting Point to Fit         :  1 @  11.94 (ft)
 2 - Length Of First Fit Section   : 25 @ 442.20 (ft)
 3 - Summing Section Increment     :  2

 Initial Estimates                                     Fit Flag
 ---------------------------------------------------------------
 11 -   1.0000 Nutation Vector                [K1]       (deg): 1 - 31
 12 -   1.0000 Precession Vector              [K2]       (deg): 1 - 32
 13 -   0.0007 Nutation Damping Exponent      [L1]      (1/ft): 0 - 33
 14 -   0.0070 Precession Damping Exponent    [L2]      (1/ft): 0 - 34
 15 - 299.0000 Nutation Vector Orientation    [P1]       (deg): 1 - 35
 16 - 273.0000 Precession Vector Orientation  [P2]       (deg): 1 - 36
 17 -  44.0000 Nutation Frequency             [W1]      (1/ft): 1 - 37
 18 -  25.0000 Precession Frequency           [W2]      (1/ft): 1 - 38
 19 -   0.0060 Nutation Frequency Change     [WD1] (deg/ft**2): 0 - 39
 20 -   0.0034 Precession Frequency Change   [WD2] (deg/ft**2): 0 - 40
 21 -   0.0000 Trim                           [K3]       (deg): 0 - 41
 22 -   0.0000 Trim Orientation               [P3]       (deg): 0 - 42

     Key in item number "," new value
     Key in "LIST" to relist "DONE" to continue
```

The distances shown in lines one and two are station locations and are output for reference purposes. Once the input data is satisfactory, enter DONE to run the analysis.

The HELP output will display the solution for the parameters and the probable error in the yaw:

```
BS87040716 40mm HEDP Tubular
28-SEP-87   16:18:26

     HELP Results
     ------------

     Yaw Error                 (deg):   0.314
     Starting Point to Fit         :   1     11.94 (ft)
     Length Of First Fit Section   :  25    442.20 (ft)
     Summing Section Increment     :   2
     Total Number of Sections      :  25    442.20 (ft)
```

Analysis Parameters

Nutation Vector	[K1]	(deg):	0.39889
Precession Vector	[K2]	(deg):	1.05130
Nutation Damping Exponent	[L1]	(1/ft):	0.00070
Precession Damping Exponent	[L2]	(1/ft):	-0.00308
Nutation Vector Orientation	[P1]	(deg):	288.82666
Precession Vector Orientation	[P2]	(deg):	274.06430
Nutation Frequency	[W1]	(deg/ft):	44.45790
Precession Frequency	[W2]	(deg/ft):	25.36411
Nutation Frequency Change	[WD1]	(deg/ft**2):	-0.00067
Precession Frequency Change	[WD2]	(deg/ft**2):	0.02859
Trim	[K3]	(deg):	0.00000
Trim Orientation	[P3]	(deg):	0.00000

:

At this point, one of the output options may be selected. A <cr> will cause the option menu to be displayed if the number desired is not known.

The following output options exist within the HELP module:

Select desired option

1 - Add section increment and continue in Help
2 - Edit input parameters

3 - Reset estimates to original
4 - Reset estimates to previous analysis

5 - Display data list (1-NT)
6 - Display yaw fit (LN-NA)

7 - Exit Help / Resume Linear Theory analysis
8 - Exit analysis program

9 - Plot Alpha vs X
10 - Theta vs X
11 - Psi vs X
12 - Theta vs Psi
13 - Theta & PSI vs X
14 - Theta vs Psi (step)

:

Option One will increment the length of the fit by the number specified in the summing section increment. The HELP routine will then be repeated for this set of conditions.

Option Two will return the program to the input menu in HELP. At this point the user may change parameter estimates or fit flags. The program will then analyze the motion for the new set of conditions.

Option Three causes the fit flags and parameter estimates to be returned to what they were when the HELP module was entered. The program will proceed to the input edit menu.

Option Four will reset the estimates to what they were before the last pass through the fitting routines. The program will return to the edit menu for user action.

Option Five will display a table of the motion data as read from the film. The following shows a partial list of this output:

Time (sec)	Down-Range Travel [X] (ft)	Horizontal Motion [Y] (feet)	Vertical Motion [Z] (feet)	Pitch [THETA] (deg)	Yaw [PSI] (deg)	Roll [PHI] (deg)	Raw Roll (deg)
0.0000000	11.9377	4.56981	0.91997	-0.04756	-1.02851	0.0	0.0
0.0050698	17.1983	4.59496	0.99552	-0.15527	0.51796	0.0	0.0
0.0147180	27.1724	4.64285	1.10731	-0.23319	-0.29336	0.0	0.0
0.0341594	47.2351	4.80058	1.32640	-0.91906	5.79866	0.0	0.0
0.0438596	57.1083	4.79740	1.43508	-0.60334	0.27905	0.0	0.0
0.0536468	67.0824	4.85454	1.54357	-0.93052	-1.11118	0.0	0.0

Option Six displays a list of the yaw fit together with the pitch and yaw from the film reading. The following shows a partial display from a reduction:

		Pitch-Missile		Yaw-Missile	
Time (sec)	Travel [X] (feet)	Experimental (deg)	Calculated (deg)	Experimental (deg)	Calculated (deg)
0.0000000	11.938	0.775	1.347	-1.302	-1.173
0.0050698	17.198	0.549	0.788	0.243	-0.160
0.0147180	27.172	0.398	0.527	-0.686	-0.251
0.0341594	47.235	-0.292	-0.106	5.503	9.754
0.0438596	57.108	0.024	-1.123	0.123	0.423
0.0536468	67.082	-0.311	-0.656	-1.445	-2.412

Option Seven will terminate the HELP function and continue Linear Theory with the current set of parameter estimates.

Option Eight will terminate the Linear Theory analysis.

Options Nine through Fourteen will create plots of the projectile motion as determined by the last pass through the data reduction. The experimental points will be superimposed on the motion plots for the length of the fit being analyzed. Figure 17 shows pitch and yaw data for travel down the range. Figure 18 shows a Theta versus Psi step plot. On the step plots the points

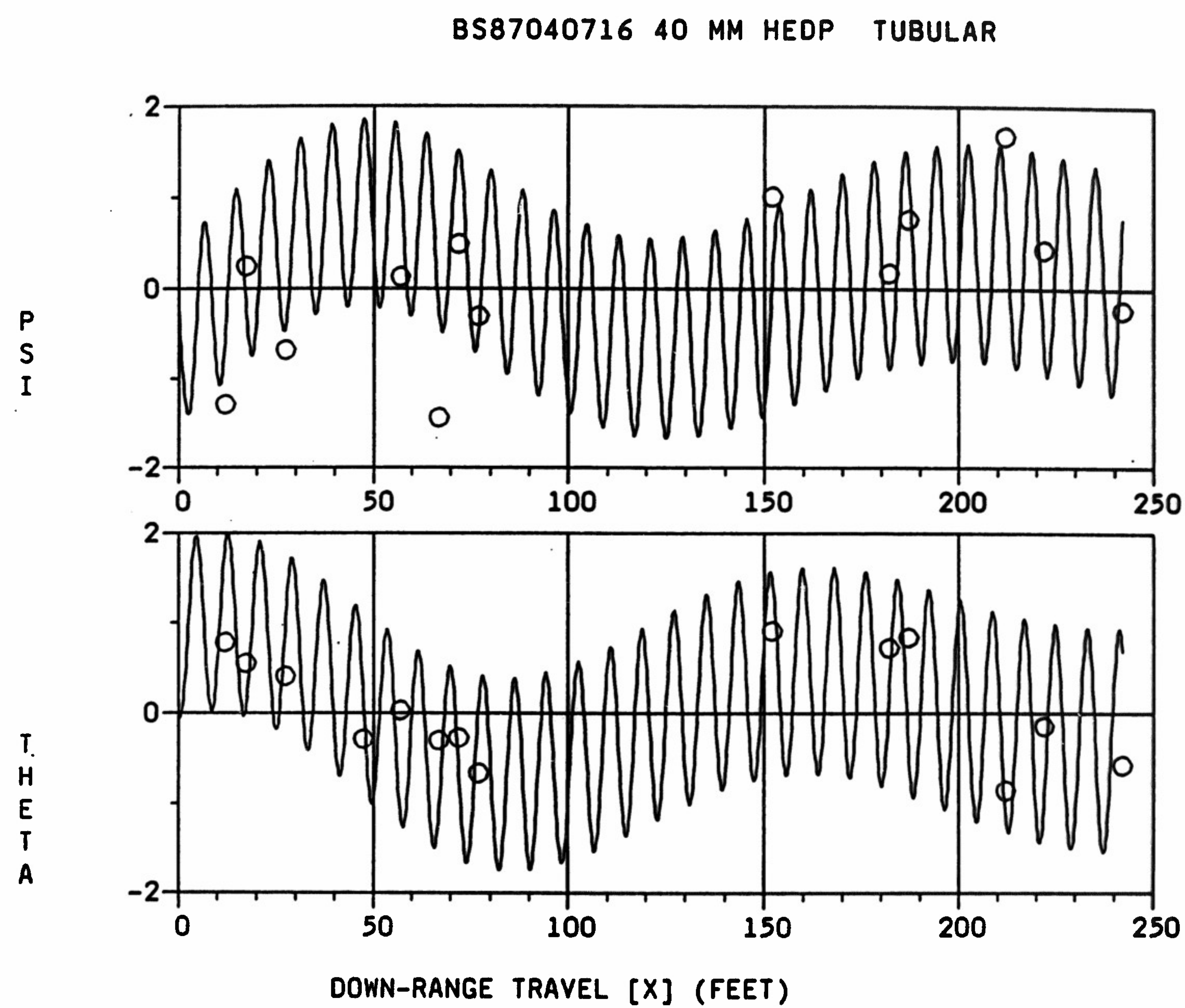


Figure 17. Linear Theory Angular Motion Fit

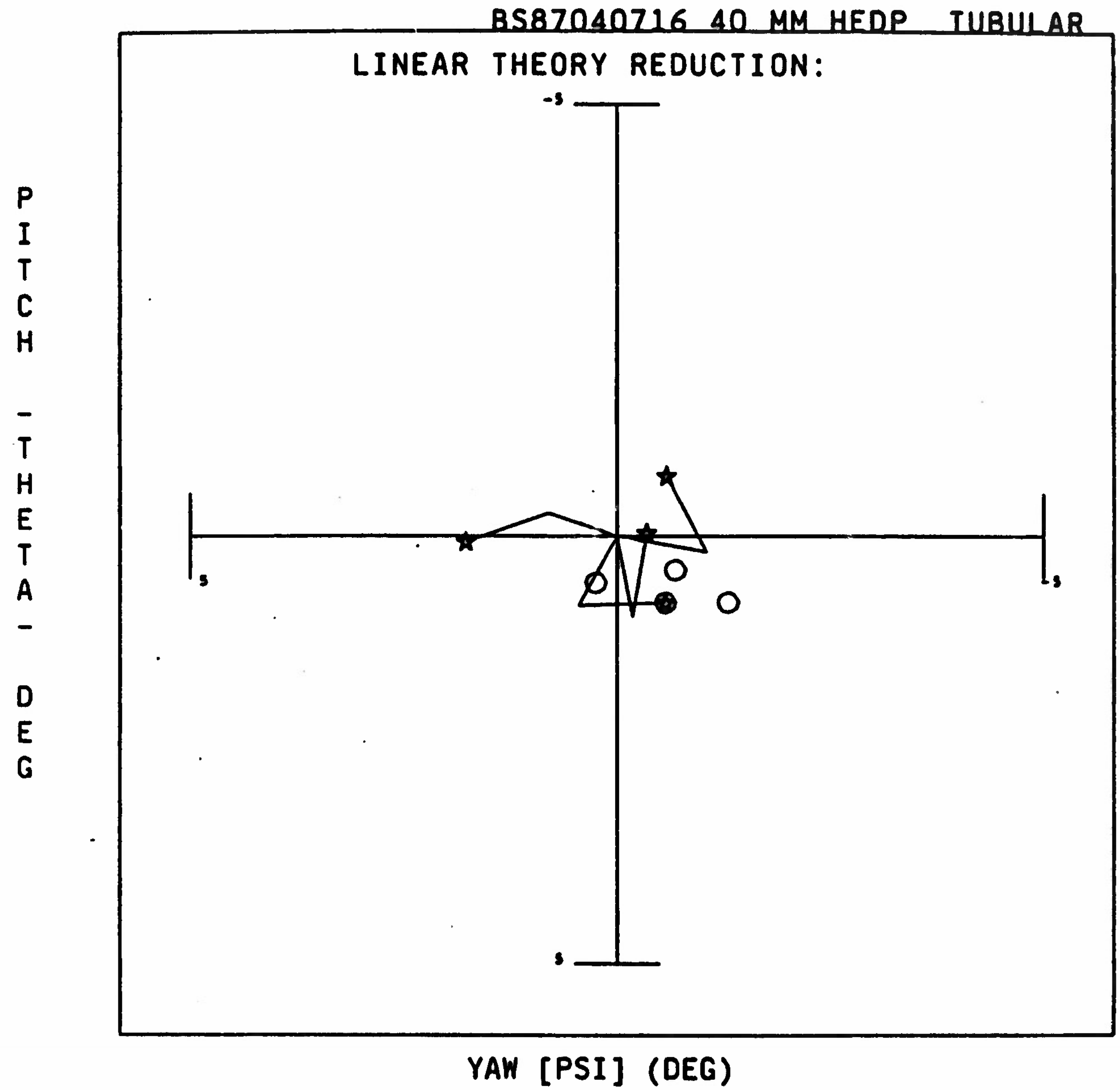


Figure 18. Linear Theory Vector Orientation

are displayed one-at-a-time with a pause for the user to type <space bar> between points. Some terminals may also require a <cr>. If any letter is typed other than <space bar> the plot will terminate there. For each point displayed in the step plot the nutation and precession vectors are drawn.

4. LINEAR THEORY ANALYSIS

Linear Theory Analysis may be run either directly from the Input module or after running the HELP module. The user will be prompted for a number of output options.

If roll data exists and the user selected the unwind option, the user has the option of examining this data.

Once the analysis has been performed, the user may examine the analysis summary. It is recommended that this data be examined before cataloging the data.

The user must select whether or not to catalog the data in the summary file. If data already exists for this shot number, it will be overwritten.

The user may choose to use the same output results for plotting. Plot data is maintained by shot number so the output data, once saved, will be available until the user decides to delete the data.

Two forms of tabulated output are available. The full printout and a summary printout. The summary printout is a subset of the full printout and is not offered for printing if the full printout has already been selected. Table 9 shows an abbreviated summary printout.

5. LINEAR THEORY OUTPUT

The output program for linear theory allows the user to create plots of the coefficients, experimental points, or integrated motion. Tabulated summaries may be made of any shot group.

The coefficient plot menu is as follows:

```
Summary Segment - Linear Theory Reductions
------------------------------------------
Shot Group 0 - 40mm HEDP
------------------------------------------

      1 - CD
      2 - CD Mach
      3 - CDO Mach
      4 - CNa
      5 - Cma
      6 - Cnpa
      7 - Cmq

     99 - Done

  :
```

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY

```
Linear Theory Input Summary
---------------------------

Shot Number: TEST25
             26-OCT-87   14:29:46

        Starting Point to Fit           [LN]:  1
        Length of First Fit Section     [NA]: 15
        Incremental Section Increment   [ND]:  0
        Summing Section Increment       [NB]: 10
        Frequency Guess              [NAUTO]:  0
        Roll Flag                    [NROLL]:  1
        Automatic Guess Flag           [NSG]:  1
        Spin Flag                    [NSPIN]:  0
        Sections Flag                [NSECT]:  1
        Shot Group Number             [IGRP]:  0

Projectile Physical Properties
------------------------------

        Diameter                              (in):      0.9790
        Axial Inertia           (in-lbf-sec**2):      0.0001430
        Transverse [Y] Inertia  (in-lbf-sec**2):      0.0013300
        Transverse [Z] Inertia  (in-lbf-sec**2):      0.0013300
        Inertial Cross Product  (in-lbf-sec**2):      0.0000000
        Weight                              (gram):    185.2911
        Center of Gravity (fraction from nose):        0.5613
        Length                                (in):      4.5570

        Roll Rate           (deg/ft):    183.7148
        Air Density       (slug/ft3):   0.0023769
        Speed of Sound      (ft/sec):     1116.53
        Reference Mach Number       :      2.9100
        Reference Center of Gravity
               (fraction from nose):      0.5613
        Reference Length        (in):      4.5570
        Number of Fins              :          1.

        CNa            :    3.08700
        Cma            :    2.73530
        Clp            :    0.00000
        Cld            :    0.00000
        CX Mach        :    0.00000
        CX2            :    2.75000
        Twist (cal/rev):   24.02000
```

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

Initial Estimates

			Parameter	Solve for Flag
Nutation Vector	[K1]	(deg):	1.00000	1
Precession Vector	[K2]	(deg):	1.00000	1
Nutation Damping Exp.	[L1]	(1/ft):	-0.00100	1
Precession Damping Exp.	[L2]	(1/ft):	-0.00100	1
Nutation Vector Orientation	[P1]	(deg):	1.00000	1
Precession Vector Orientation	[P2]	(deg):	1.00000	1
Nutation Frequency	[W1]	(deg/ft):	17.38780	1
Precession Frequency	[W2]	(deg/ft):	2.36120	1
Nutation Frequency Change	[WD1]	(deg/ft**2):	0.00000	0
Precession Frequency Change	[WD2]	(deg/ft**2):	0.00000	0
Trim Vector	[K3]	(deg):	0.00000	0
Trim Vector Orientation	[P3]	(deg):	0.00000	0

Tunnel XYZ Input Data (partial list)

Time (sec)	Down-Range Travel [X] (ft)	Horizontal Motion [Y] (ft)	Vertical Motion [Z] (ft)	Raw Roll [PHI] (deg)	Pitch [THETA] (deg)	Yaw [PSI] (deg)
0.0000000	7.3086	-0.00068	0.00137	262.1	-2.002	3.751
0.0014470	12.5220	0.00261	-0.00019	142.5	-4.708	1.057
0.0026045	16.6885	0.00648	0.00232	189.6	-3.380	-2.104
0.0054985	27.0960	0.01116	0.01264	307.5	-1.692	1.765
0.0109970	46.8224	0.01699	0.04528	344.7	-0.070	0.375
0.0138910	57.1808	0.01475	0.06754	100.2	-1.693	-4.184
0.0167850	67.5217	0.00915	0.09079	215.0	1.501	0.354

Drag Estimate --

LN = 1 N = 50 NC = 4

Sum of Residuals	Probable Error
0.0001576	0.0012485
0.0000000	0.0000005
0.0000000	0.0000005

	Value	Probable Error
D1:	-0.101E-05	0.212E-06
D2:	0.277E-03	0.298E-08
D3:	0.218E-07	0.111E-10
D4:	0.147E-11	0.115E-13

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

J	NP	Weight Factor	Down-range Travel (ft)	Raw Roll (deg)	Unwound Roll (deg)	Roll Rate (deg/ft)	ADIFF	ERROR	R1	R2	R3	R4	Roll Error (deg)
1	1	1.0	7.31	262.1	262.1	183.7	0.6	0.0	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
2	2	1.0	12.52	142.5	1222.5	183.7	0.5	-2.6	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
3	3	1.0	16.69	189.6	1989.6	183.7	0.5	-4.3	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
4	4	1.0	27.10	307.5	3907.5	183.7	0.5	-10.2	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
5	5	1.0	46.82	344.7	7544.7	183.7	0.6	-23.3	36262.	183.71	0.00000E+00	0.00000E+00	0.00000E+00
6	6	1.0	57.18	100.2	9460.2	184.3	0.7	-6.9	36261.	184.31	0.00000E+00	0.00000E+00	0.55121

Experimentel Trajectory Deta Points

Time (sec)	Down-range Travel [X] (feet)	Horizontel Motion [Y] (feet)	Vertical Motion [Z] (feet)	Pitch Missile [THETA] (deg)	Yaw Missile [PSI] (deg)	Unwound Roll [PHI] (deg)	Pitch Fixed-Plene [THETA] (deg)	Yaw Fixed-Plane [PSI] (deg)	Raw Roll [PHI] (deg)
0.0000000	7.3086	-0.00068	0.00137	-1.995	3.739	262.1	-2.002	3.751	262.1
0.0014470	12.5220	0.00261	-0.00019	-4.688	1.036	1222.5	-4.708	1.057	142.5
0.0026045	16.6885	0.00648	0.00232	-3.348	-2.129	1989.6	-3.380	-2.104	189.6
0.0054985	27.0960	0.01116	0.01264	-1.630	1.737	3907.5	-1.692	1.765	307.5
0.0109970	46.8224	0.01699	0.04528	0.036	0.374	7544.7	-0.070	0.375	344.7
0.0138910	57.1808	0.01475	0.06754	-1.575	-4.160	9460.2	-1.693	-4.184	100.2

Linear Theory Analysis Finel Results

Time (sec)	Time Error (micro sec)	Down-Range Trevel [X] (feet)	Horizontal Motion [Y] (feet)	Y Error (feet)	Verticel Motion [Z] (feet)	Z Error (feet)	Velocity (ft/sec)
0.0807414	0.59	291.8115	-0.22228	-0.00102	0.22759	0.00066	3445.3
0.0850823	0.81	306.7485	-0.23489	0.00034	0.22330	-0.00091	3437.1
0.0894232	0.89	321.6506	-0.24307	0.00144	0.22054	-0.00005	3428.9
0.0937641	0.44	336.5192	-0.25129	0.00026	0.22035	0.00188	3420.8
0.0983945	0.77	352.3379	-0.25863	-0.00038	0.21975	-0.00054	3412.2
0.1070763	0.75	381.8923	-0.27452	-0.00058	0.23152	-0.00051	3396.2
0.1117067	0.31	397.5996	-0.28668	0.00068	0.23761	-0.00045	3387.6

Time Error (micro sec)	Down-Range Travel Error [X] (feet)	Swerve Error [Y-Z] (feet)
0.5297	0.0018	0.0007

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONTINUED)

Linear Theory Analysis Summary : Page 1

Projectile Physical Properties

Diameter	0.979 (in)	24.87 (mm)
Weight	0.408 (lbm)	185.29 (gram)
Axial Inertia	0.055 (lbm-in2)	161.57 (gm-cm2)
Transverse [Y] Inertia	0.513 (lbm-in2)	1502.70 (gm-cm2)
Transverse [Z] Inertia	0.513 (lbm-in2)	1502.70 (gm-cm2)
Inertial Cross product	0.000 (lbm-in2)	0.00 (gm-cm2)
Length	4.557 (in)	11.575 (cm)

Center of Gravity (fraction from nose) 0.5613

Air Properties

Density	0.0023769 (slug/ft3)	0.0012250 (gm/cm3)
Speed of Sound	1116.53 (ft/sec)	340.32 (m/sec)

Reynolds Number	8256479.
Temperature (Deg C)	14.9989
Pressure (mbar)	1012.9569
Relative Humidity	0.0000

Linear Theory Analysis Summary : Page 2

Starting point to fit	[LN]	:	1.	1.	15.	27.
Number of Stations in Fit	[N]	:	50.	27.	37.	50.
Length of first section to fit	[NA]	:	50.	27.	23.	24.
Total Number of Stations	[NT]	:	50.	50.	50.	50.
Nutation Vector	[K1]	(deg):	2.5783	2.5328	2.6845	2.5879
Precession Vector	[K2]	(deg):	2.4382	2.4858	2.0594	2.2071
Nutation Damping Exponent	[L1]	(1/ft):	-0.000660	-0.000513	-0.000790	-0.000678
Precession Damping Exponent	[L2]	(1/ft):	-0.003402	-0.003645	-0.002805	-0.003066
Nutation Vector Orientation	[PHI1]	(deg):	85.59	84.64	90.62	93.66
Precession Vector Orientation	[PHI2]	(deg):	149.34	150.09	131.54	168.69
Nutation Frequency	[W1]	(deg/ft):	17.5108833	17.5243473	17.4876423	17.4679527
Precession Frequency	[W2]	(deg/ft):	2.2718909	2.2435167	2.4046700	2.1866343
Nutation Freq. Change	[WD1]	(deg/ft2):	0.0025113	0.0024569	0.0025483	0.0026129
Precession Freq. Change	[WD2]	(deg/ft2):	-0.0002248	0.0000228	-0.0006820	-0.0000470
Trim Vector	[K3]	(deg):	0.0000000	0.0000000	0.0000000	0.0000000
Trim Vector Orientation	[PHI3]	(deg):	0.0000000	0.0000000	0.0000000	0.0000000

TABLE 9. LINEAR THEORY ANALYSIS SUMMARY (CONCLUDED)

Swerve Constant	[S1]	:	0.0006181	0.0006181	0.0006181	0.0006181
Swerve Constant	[S2]	(1/ft):	0.0375046	0.0389002	0.0327238	0.0339633
Roll Constant	[R1]	:	262.3717	263.4615	249.1992	277.1478
Roll Constant	[R2]	(1/ft):	183.9213	183.8760	184.0632	183.8345
Roll Constant	[R3]	(1/ft**2):	0.0103441	0.0106711	0.0098738	0.0105046
Probable Error in Distance	[PE-X]	(ft):	0.0016209	0.0016212	0.0012824	0.0017719
Probable Error in Angle	[PE-A]	(deg):	0.0636649	0.0689415	0.0611934	0.0525243
Probable Error in Swerve	[PE-S]	(ft):	0.0009292	0.0008928	0.0007941	0.0006600
Probable Error in Time	[PE-T]	(msec):	0.4737	0.4601	0.3731	0.5297
Probable Error in Roll	[PE-R]	(deg):	0.7583	0.7637	0.7953	0.6236
Distance to First Fit Station	[X-LN]	(ft):	7.3086	7.3086	156.7715	291.8115
Distance to Last Fit Station	[X-N]	(ft):	662.4832	291.8115	457.1191	662.4832
Del Bar Squared	[DBSQ]	:	5.7680	8.1690	5.4176	3.9147
	[DBEF]	:	9.7690	13.7618	10.2747	7.7839
	[DBEP]	:	9.2684	13.2795	9.7676	7.3559

Linear Theory Analysis Summary : Page 3

Mach Number	[MACH]	:	3.0646	3.1562	3.0783	2.9957
Cma	[CMA]	:	2.6846	2.6750	2.6750	2.6956
Cmq	[CMQ]	:	-13.6765	-14.1923	-11.1757	-11.9708
Cnpa	[CNPA]	:	0.9209	1.0288	0.6213	0.7535
CD	[CD]	:	0.3258	0.3237	0.3255	0.3270
CD0	[CD0]	:	0.3157	0.3090	0.3159	0.3203
CD Mach	[CDM]	:	0.3258	0.3237	0.3255	0.3270
CD0 Mach	[CDM0]	:	0.3157	0.3090	0.3159	0.3203
CNa	[CNA]	:	2.9770	3.1413	3.0694	2.8986
Roll Computed Clp	[CLPR]	:	-0.0265	-0.0258	-0.0266	-0.0265
Frequency Computed Clp	[CLPW]	:	-0.0277	-0.0203	-0.0392	-0.0213
Gyro Stability	[GYRO]	:	2.6150	2.5203	2.6038	2.6882
Dynamic Weight Factor	[TAU]	:	1.2725	1.2875	1.2742	1.2619
Velocity at Mid-Range	[VMID]	(ft/sec):	3421.7085	3523.9824	3436.9805	3344.8425
Mid-Range Distance	[XMID]	(ft):	334.8959	149.5600	306.9453	477.1474
Reference Distance	[XREF]	(ft):	7.3086	7.3086	7.3086	7.3086
Reference Mach Number	[MREF]	:	2.9100	2.9100	2.9100	2.9100
Yaw of Repose	[YREP]	(deg):	0.0045959	0.0042614	0.0045535	0.0048665
Initial Velocity	[VZRO]	(ft/sec):	3604.0483	3604.0483	3604.0483	3604.0483

Figure 19 shows a plot of the linear theory drag coefficients from a reduction of 40mm projectiles.

The following menu is available for experimental point plotting:

```
            Linear Theory Experimental Point Plots
            --------------------------------------

                 1 - Time
                 2 - Horizontal Motion [Y]
                 3 - Vertical Motion    [Z]
                 4 - Pitch          [THETA]
                 5 - Yaw              [PSI]
                 6 - Roll             [PHI]
                 7 - Pitch/Yaw [THETA-PSI]
                 8 - Pitch/Yaw Step Plot

                99 - Done
            :
```

The experimental points will be superimposed on the motion plots. A plot of experimental data was shown in Figure 3.

The following menu is available for the motion plots:

```
              Enter the number for the desired plot

                 1 - Angle of Attack [ALPHA] vs Travel [X]
                 2 - Pitch           [THETA] vs Travel [X]
                 3 - Yaw               [PSI] vs Travel [X]
                 4 - Pitch           [THETA] vs Yaw    [Psi]

                 5 - Theta & Psi vs X

                99 - Done

              :
```

Figure 17 in the Linear Theory HELP paragraph shows a plot of the same form as will be created here. The code for plotting in the HELP option is the same as was used for these output plots.

Summary tables are created by shot group number. For the linear theory program the summary tables are sorted by both shot number and Mach number. Table 10 shows part of the Mach number sort of a linear theory summary.

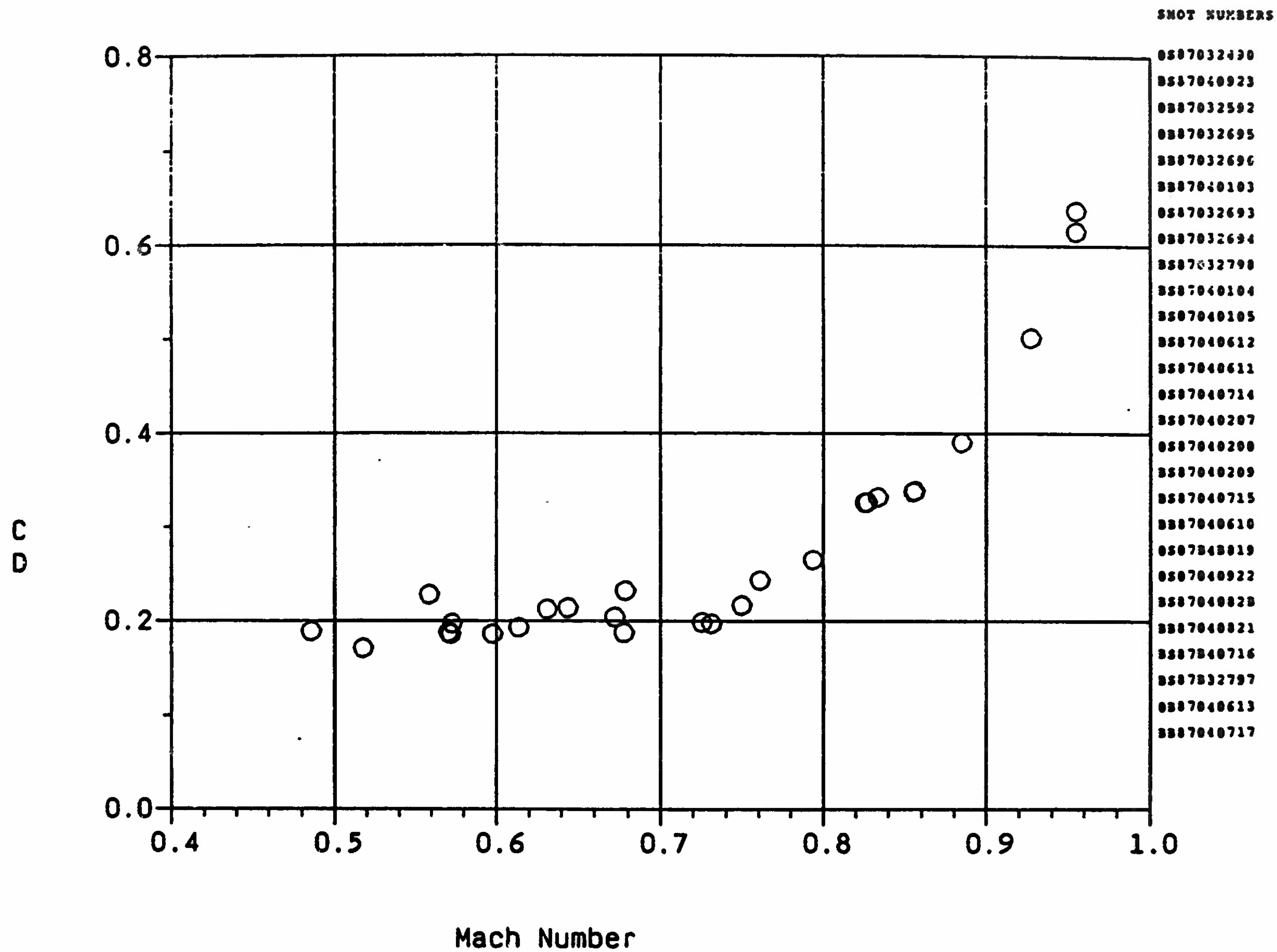


Figure 19. Linear Theory Coefficient Plot

TABLE 10. LINEAR THEORY SUMMARY OUTPUT

Linear Theory Summary Output
Shot Group Number 0

Sort by Mach Number

Shot Number	Projectile Diameter (cm)	Mass (grams)	Axial Inertia (gm-cm2)	Inertia Y (gm-cm2)	Inertia Z (gm-cm2)	Inertia XY (gm-cm2)	Length (cm)	CG (percent)	CG (cm from nose)	Roll (pins)
BS 87032798	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
BS 87032490	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
BS 87032797	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
BS 87032694	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
BS 87032693	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO
BS 87032592	3.9563	244.78	593.170	1190.9	1190.9	0.000000	7.834	0.6120	4.795	NO

Shot Number	No. of Stations	Observed Distance (m)	Air Density (gm/cm3)	Speed of Sound (m/sec)	Reynolds Number	X (m)	Probable Error Swerve (m)	Probable Error Angle (deg)	Roll (deg)
BS 87032798	31	131.2	0.0011970	343.02	862168.	0.0014	0.0018	0.29	0.00
BS 87032490	32	132.6	0.0011970	343.02	918385.	0.0008	0.0009	0.36	0.00
BS 87032797	26	131.2	0.0011970	343.02	1003990.	0.0007	0.0019	0.32	0.00
BS 87032694	31	131.2	0.0011980	343.02	1012720.	0.0012	0.0011	0.33	0.00
BS 87032693	14	76.2	0.0011980	343.02	1015440.	0.0011	0.0007	0.37	0.00

Shot Number	Mach Number	DBSQ (deg**2)	Nutation Vector [K10] (deg)	Precession Vector [K20] (deg)	Nutation Damping [L1] (deg/m)	Precession Damping [L2] (1/m)	Nutation Frequency [W10] (deg/m)	Precession Frequency [W20] (deg/m)	Nutation Change [WD1] (deg/m2)	Precession Change [WD2] (deg/m2)
BS 87032798	0.486	15.5	2.34	3.29	-0.00064	-0.00022	147.387	6.830	0.05738	-0.00460
BS 87032490	0.518	2.4	0.84	0.38	0.00713	0.00574	139.552	5.034	0.05015	0.02478
BS 87032797	0.559	53.7	6.84	5.57	-0.00244	-0.00401	148.448	6.824	0.07784	-0.00296
BS 87032694	0.570	14.5	3.32	2.43	-0.00084	-0.00205	146.888	7.289	0.05354	-0.00499
BS 87032693	0.572	12.3	3.16	1.25	0.00014	0.00448	148.473	6.912	0.07363	0.00519

TABLE 10. LINEAR THEORY SUMMARY OUTPUT (CONCLUDED)

Shot Number	Mach Number	Orientation of Yaw vector (deg)	Yaw of Repose (deg)	Gyro Stability	Roll Fit Spin (deg/m)	Frequency Fit Spin (deg/m)
BS 87032798	0.49	0.00	0.19	6.30	305.12	309.61
BS 87032490	0.52	0.00	0.16	5.86	305.12	290.27
BS 87032797	0.56	0.00	0.14	6.30	305.12	311.73
BS 87032694	0.57	0.00	0.13	5.91	305.12	309.53
BS 87032693	0.57	0.00	0.12	5.83	305.12	311.95

Shot Number	Mach Number	DBSQ	CD	CD0	CDSQ	CNa	Cma	Cmq	Cnpa	Roll Fit Clp	Frequency Fit Clp
BS 87032798	0.486	15.5	0.188	0.169	4.040	1.740	1.230	1.1	-0.595	0.000	-0.024
BS 87032490	0.518	2.4	0.170	0.167	3.812	1.512	1.189	3.9	-1.217	0.000	-0.001
BS 87032797	0.559	53.7	0.226	0.158	4.178	1.878	1.269	-0.1	-0.213	0.000	-0.022
BS 87032694	0.570	14.5	0.187	0.169	4.018	1.715	1.304	0.6	-0.414	0.000	-0.026
BS 87032693	0.572	12.3	0.185	0.171	3.932	1.632	1.339	2.2	-1.060	0.000	-0.006

Shot Number	Mach Number	DBSQ	Ref Mach Number	CDR	CD0R	CDSQ	CDM
BS 87032798	0.486	15.5	0.600	0.188	0.169	4.040	0.000
BS 87032490	0.518	2.4	0.600	0.170	0.167	3.812	0.000
BS 87032797	0.559	53.7	0.600	0.226	0.158	4.178	0.000
BS 87032694	0.570	14.5	0.600	0.187	0.169	4.018	0.000
BS 87032693	0.572	12.3	0.600	0.185	0.171	3.932	0.000

Muzzle exit values

Shot Number	Mach Number	Nutation Vector (K10m) (deg)	Precession Vector (K20m) (deg)	Nutation Orientation (P1m) (deg)	Precession Orientation (P2m) (deg)	Nutation Frequency (W10m) (deg/m)	Precession Frequency (W20m) (deg/m)	First Max Yaw (deg)	Distance From Muzzle (m)	Orientation (deg)
BS 87032798	0.486	2.34	3.29	84.097	28.559	147.179	6.847	5.631	0.000	0.000
BS 87032490	0.518	0.83	0.37	278.082	113.095	139.444	4.981	1.214	1.450	120.319
BS 87032797	0.559	6.90	5.65	140.972	98.746	148.169	6.835	12.458	0.000	0.000
BS 87032694	0.570	3.33	2.45	-21.834	253.953	146.694	7.308	5.761	0.000	0.000
BS 87032693	0.572	3.16	1.23	116.267	44.857	148.206	6.893	4.401	2.042	58.933

SECTION VII

SIX DEGREE OF FREEDOM (6 DOF)

1. SIX DOF INPUT

The 6 DOF reduction is split into separate input, analysis, and output programs. The input program creates a named data file for execution by the analysis. The analysis will always run the latest data configuration from the input program.

The first step in setting up the input file for the 6 DOF analysis program is to select the number of shots to be reduced together. Up to five shots may be reduced in a multiple fit:

Enter number of shots in 6 DOF analysis: 1

Next the desired shots are identified:

Key in 10 digit 6 DOF projectile title (or LIST)
: BS87040818

The LIST option will display all of the shot numbers available for a specified shot group. A negative shot group number will display all shots.

An automatic fit option is available on request. This option will allow logic within the program to turn on fit flags based on the reduction and projectile configuration:

Do you want to exercise the automatic fit option (Y/N)? N

If the selected shot(s) have been reduced before, the initial estimates for this reduction may be those used for the previous reduction. If this option is selected, the accuracy of the previous reduction will be displayed and the user prompted on whether or not they shall be used:

Do you want to update initial estimates based on
previous 6 DOF reduction on specified shot(s) (Y/N)? Y

Initial estimate update based on 6 DOF - reduction of:
Date 8-SEP-87 Time 19:35:18

Probable errors of fit to the data were:

X (m)	Y-Z (m)	Theta-Psi (deg)	Phi (deg)
0.003751	0.002992	0.748300	0.000000

Do you want to update (Y/N)? N

Three forms of parameters must be defined for the analysis: the data grouping and update options, initial estimates, and fit flags. Initial estimates and fit flags must be defined for the first fit. Subsequent fits which turn on additional coefficients may also be defined.

The grouping and update menu is:

```
Fixed Plane Analysis 6-DOF Input

          Sectional Fit Options (Single Fit Only)
          _______________________________________

1 - Data points in first section (NA)................    15
2 - Data points added to each section (NB)...........    10

               6D Summary / Update Options
               ___________________________

3 - Group number code................................     0
4 - 6 DOF - Summary(1, 2, or 3).......................     3
5 - 6 DOF - Initial estimate update(1, 2, or 3)......     3

(1 : no update)        (2 : fit option selection)
(3 : program criteria)

                     Miscellaneous
                     _____________

6 - Integration time step                   (sec) .00043000

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE
```

Options One and Two define how many data points within the range will be reduced together during the fit. Option Three requires the user to specify the group code numbers for cataloging the 6 DOF results. Options Four and Five signal the program for updating the summary file. Criteria One causes no update to be made to the summary file. Criteria Two causes an update based on the setting of two fit flags. Criteria Three causes an update to the summary file if a 10 percent improvement in the probable error occurs. Option Six allows the computed integration time step to be changed.

The next input option allows for changing the initial estimates that were passed to 6 DOF from the linear theory reduction program:

```
Do you want to change initial estimates (Y/N)? Y

 Initial Estimates for Shot Number: BS87040818

  1 - Cma        :   1.13
  2 - Cma3       :  0.000E+00
  3 - Cma5       :  0.000E+00
      .
      .
      .
 32 - Cnga3      : 0.0000E+00
 33 - Cmga       : 0.0000E+00
 34 - Cnga       : 0.0000E+00

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE
```

The above list contains a partial selection of the input parameters. In fact, the coefficient input is split into two menus. An example taken from the second menu is:

```
  1 - Pitch Angle (+ down) [THETA]      (deg):  -1.87
  2 - Pitch Rate                    (deg/sec):  -165.
  3 - Yaw (+ left) [PSI]                (deg):  0.930
  4 - Yaw Rate                      (deg/sec):  -823.
  5 - Horizontal Range [X]             (feet):   11.9
      .
      .
      .
 17 - CNdB                                   :  0.000E+00
 18 - CmdA                                   :  0.000E+00
 19 - CmdB                                   :  0.000E+00
 20 - CX0-unique                             :  0.000E+00
 21 - Clp-unique                             :  0.000E+00

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE
```

Once the initial estimates are set the initial fit options may be modified:

```
Do you want to change fit options (Y/N)? Y

 Fit Flags for Shot Number: BS87040818
 40 MM HEDP  TUBULAR

  1 - Cma        : 1
  2 - Cma3       : 0
  3 - Cma5       : 0
      .
      .
      .
 32 - Cnga3      : 0
 33 - Cmga       : 0
 34 - Cnga       : 0

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE
```

Here too, the initial fit flag menu takes two pages:

```
 Fit Flags for Shot Number: BS87040818
 40 MM HEDP  TUBULAR

  1 - Pitch Angle (+ down)     [THETA] : 1
  2 - Pitch Rate           [THETA-DOT] : 1
  3 - Yaw (+ left)               [PSI] : 1
  4 - Yaw Rate               [PSI-DOT] : 1
  5 - Horizontal Range             [X] : 1
      .
      .
      .
 17 - CYg0                             : 0
 18 - Cmg0                             : 0
 19 - Cng0                             : 0
 20 - CX0-unique                       : 0
 21 - Clp-unique                       : 0

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE
```

Once the initial fit flags are set the user may define up to 10 subsequent sets of fit flags. The menu for subsequent fits is different from the menu

for the initial fit. Appendix B contains a complete list of the coefficients and the associated line numbers. Here all options appear on one page and not all options are available:

```
Do you want subsequent fit options (Y/N)?

 Fit Option # 2
  1 - Cma        : 1
  2 - Cma3       : 0
  3 - Cma5       : 0
  4 - Cmq        : 1
  5 - Cmq2       : 0
      .
      .
      .
 32 - Cnga3      : 0
 33 - Cmga       : 0
 34 - Cnga       : 0

 35 - Cma-unique                    : 0
 36 - Inertial Form Factor [IX/IY]  : 1
 37 - Cl-DEL fin cant roll moment   : 0
 38 - CNdA                          : 0
 39 - CNdB                          : 0
 40 - CmdA                          : 0
 41 - CmdB                          : 0
 42 - CX0-unique                    : 0
 43 - Clp-unique                    : 0

Key in item number "," new value
Key in "LIST to relist "DONE" to continue
: DONE

Do you want subsequent fit options (Y/N)? N
```

The input program is terminated as soon as no further subsequent fits are requested.

2. SIX DOF ANALYSIS

The 6 DOF Analysis program may be run in either interactive or batch mode. When running in a batch mode, the user will be prompted to enter a unique file name. The input data file will be copied to a file with this name. This is necessary to maintain unique file names when multiple processes are running. When running in the interactive mode, the program will run the data as last configured by the input program. The user will see the input data echoed, parameter values input during the analysis, and an analysis summary. The program may be aborted out of the interactive mode by typing <CTRL C>. The user may then restart the analysis in a batch mode.

The interactive analysis mode gives the user the capability of modifying the fit during the analysis. Using the initial estimates and fit options selected in the input program, a reduction is performed and the probable errors printed out:

Probable Errors of Fit — Fit Option: 1

Fit	Pitch-Yaw (deg)	Roll (deg)	Travel [X] (feet)	Swerve [Y-Z] (feet)
1	0.40402	0.00000	0.00531	0.00893
2	0.33277	0.00000	0.01081	0.00549
3	0.32895	0.00000	0.00162	0.00534
4	0.32893	0.00000	0.00161	0.00534

Following the probable errors, the values of the coefficients used for each fit will be printed:

Summary of Aerodynamic Coefficients During Fit

1 Cma	:	1.26880	1.27731	1.27708	1.27707
4 Cmq	:	-0.11800	0.28712	0.27919	0.27675
6 Cnpa	:	-0.23880	-0.42858	-0.43711	-0.43760
17 CX0	:	0.16070	0.15089	0.15072	0.15088
20 CNa	:	1.90340	1.99709	2.00090	2.00133
32 Clp	:	-0.02090	-0.01120	-0.01186	-0.01186

•
•
•

The coefficients should be examined to see if a solution is being converged on. If the values from fit to fit are oscillating, the parameter should be fixed.

After this table is printed, another table of the fit parameters and their associated probable errors will be displayed:

Final Coefficients — Fit Option: 1
At average Mach number unless noted

		Parameter	Probable Error	Fit Flag
1 Cma	:	1.27707	0.01158	1 : 201
4 Cmq	:	0.27675	0.29260	1 : 204
6 Cnpa	:	-0.43760	0.09651	1 : 206
7 Cnpa3	:	5.54210	0.00000	0 : 207
17 CX0	:	0.15088	0.00208	1 : 217
18 CXa2	:	2.30000	0.00000	0 : 218
20 CNa	:	2.00133	0.03661	1 : 220

```
Final Coefficients -- Fit Option: 1 - (Continued)

 23 CYpa         :     -1.00000          0.00000        0 : 223
 32 Clp          :     -0.01186          0.00525        1 : 232

146 Fit section        : 10
147 Section increment  :  5
    Total data points  : 26

Key in item number "," new value
"LIST"  to relist               "ABORT" to abort
"DONE"  to increment fit        "HELPLESS" to end HELP
"RERUN" for same fit length

 :
```

At this point in the program, parameters may be changed again. Fit options may also be turned on or off. The numbers along the left side allow the user to modify a parameter. The numbers along the right allow the user to change fit flags. All non-zero parameters will be displayed. Values or fit flags other than those displayed may be changed but the user must either know the parameter number or refer to the list in Appendix B. Note the numbers in the right column are the same as the left column with 200 added.

The RERUN option will allow the analysis to be repeated for the same number of tunnel stations with the modified parameters and flags. The DONE option will also use the modified parameters and flags but will increment the number of stations by the summing section increment. The ABORT option will terminate the analysis program. The HELPLESS option will allow the analysis to continue from this point without displaying this change menu again. The program will complete this fit and any subsequent fits as defined by the input program.

The change menu will only appear during the first fit of the data. Fit options during subsequent fits come from the input data file.

3. SIX DOF OUTPUT

The 6 DOF output program allows for the creation of summary tables, motion plots, and coefficient plots. The output menu is:

```
  AERODAS 6 DOF Output Segment
 ------------------------------
  1  Summary Tables (Terminal)
  2  Summary Tables (Lineprinter)

  3  Motion Plots
  4  Coefficient Plots

  5  Exit Output Program
 :
```

If summary tables are requested, the shot group to be output must be specified. The summary file will be sorted for the single and multiple

reductions for this group number. The user may select, from the shots, which ones to include in the summary. Table 11 shows a summary of 40mm, spin stabilized, shot reductions.

Coefficient plots are also created by shot group numbers. For the shots selected from the desired shot group, the following menu of plots is available:

```
Summary Segment - Six Degree of Freedom Reductions
-------------------------------------------------------
SHOT GROUP    1 - Sample Output
-------------------------------------------------------
vs Mach Number                  vs Angle of Attack
 1 - CXO                            CX  - 11
 2 - CNa                            CN  - 12
 3 - Cma                            Cm  - 13
 4 - Cnpa                           Cnp - 14
 5 - Cmqa                           Cmq - 15
 6 - Clp
 7 - CXa2
 8 - Cma3
 9 - Cnpa3
99 - Done
:
```

Plots versus Mach number are for the single shot reductions. Plots versus angle of attack are for multiple shot reductions. Figures 20 and 21 show drag coefficients in both plot modes.

When a motion plot is to be created, the program reads the coefficients for the specified single or multiple shot reduction. These coefficients are then displayed for modification by the user. Each of the shots will be integrated through its trajectory. Probable errors for each shot in the reduction will be displayed prior to the display of the following plot menu:

```
Plot Segment - Six Degree of Freedom Reductions
-------------------------------------------------
SHOT GROUP    1 - Sample Output
-------------------------------------------------
Plot #   Description        Plot #  Description
  1         Y vs X             8    Residual in X vs X
  2         Z vs X             9    Residual in Y vs X
  3       Phi vs X            10    Residual in Z vs X
  4     Theta vs X            11    Residual in Phi vs X
  5       Psi vs X            12    Residual in Theta vs X
  6     Alpha vs X            13    Residual in Psi vs X
  7     Theta vs Psi          14    Velocity vs X
 19 Theta & Psi vs X
 20 Change Shot Number
 21 Print tabulated data on exit
 99 Done
:
```

TABLE 11. 6 DOF SUMMARY

6 DOF Summary Output
Shot Group Number: 0

Shot Number	Date	Time	Ref. CG (cm)	Ref. CG%	Ref. Length (cm)	Ref. Mach Number	Mach Number	DBSQ (deg2)	Max Angle of Attack (deg)	Probable Error X (m)	Probable Error Y-Z (m)	Probable Error Angle (deg)	Probable Error Roll (deg)
BS87032798	27-JUL-87	12:25:36	4.80	0.612	7.83	0.49	0.487	15.230	5.7	0.0015	0.0017	0.340	0.00
BS87032490	30-JUL-87	14:47:47	4.80	0.612	7.83	0.52	0.518	2.233	2.3	0.0008	0.0014	0.381	0.00
BS87032797	26-OCT-87	12:02:45	4.80	0.612	7.83	0.56	0.561	52.870	11.6	0.0013	0.0022	0.358	0.00
BS87032694	27-JUL-87	13:35:57	4.80	0.612	7.83	0.57	0.571	14.328	5.7	0.0013	0.0014	0.318	0.00
BS87032693	30-JUL-87	15:04:57	4.80	0.612	7.83	0.57	0.572	12.260	4.8	0.0011	0.0009	0.377	0.00
BS87032592	7-AUG-87	08:03:16	4.80	0.612	7.83	0.57	0.573	14.618	4.7	0.0008	0.0013	0.401	0.00
BS87032696	27-JUL-87	14:24:19	4.80	0.612	7.83	0.60	0.598	1.521	2.4	0.0011	0.0034	0.352	0.00

Shot Number	Mach Number	DBSQ / ABARM	CX / CX2	CNa / CNa3	CYpa / CYpa3	Cma / Cma3	Cmq / Cmq2	Cnpa / Cnpa3	Clp / IX/IY	CXM / CmaM	Probable Error X(m) / Y-Z(m)	Probable Error Angle(deg) / Roll(deg)
BS87032798	0.487	15.2	0.170	1.761	-1.00	1.219	0.3	-0.34	-0.0218	0.00	0.0015	0.340
		5.7	2.300	0.000	0.00	0.000	0.0	0.00	0.5041	0.00	0.0017	0.000
BS87032490	0.518	2.2	0.167	1.774	-1.00	1.125	1.9	-0.32	-0.0202	0.00	0.0008	0.361
		2.3	2.300	0.000	0.00	0.000	0.0	0.00	0.4789	0.00	0.0014	0.000
BS87032797	0.561	52.9	0.161	1.903	-1.00	1.269	-0.1	-0.24	-0.0209	0.00	0.0013	0.358
		11.6	2.300	0.000	0.00	0.000	0.0	5.54	0.5061	0.00	0.0022	0.000
BS87032694	0.571	14.3	0.170	1.676	-1.00	1.302	0.2	-0.22	-0.0238	0.00	0.0013	0.318
		5.7	2.300	0.000	0.00	0.000	0.0	0.00	0.5042	0.00	0.0014	0.000
BS87032693	0.572	12.3	0.170	1.786	-1.00	1.274	1.5	-0.66	-0.0088	0.00	0.0011	0.377
		4.8	2.300	0.000	0.00	0.000	0.0	0.00	0.5084	0.00	0.0009	0.000
BS87032592	0.573	14.6	0.146	1.818	-1.00	1.305	0.3	-0.25	-0.0254	0.00	0.0008	0.401
		4.7	9.414	0.000	0.00	0.000	0.0	0.00	0.5046	0.00	0.0013	0.000
BS87032696	0.598	1.5	0.183	2.287	-1.00	1.272	5.1	-2.02	-0.0014	0.00	0.0011	0.352
		2.4	2.300	0.000	0.00	0.000	0.0	0.00	0.4740	0.00	0.0034	0.000

TABLE 11. 6 DOF SUMMARY (CONCLUDED)

Shot Numbers		Date	Time	Ref. Mach Number	Mach Number	DBSQ (deg2)	Max Angle of Attack (deg)	Probable Error X (m)	Probable Error Y-Z (m)	Probable Error Angle (deg)	Probable Error Roll (deg)
BS87032490 BS87032797	BS87032798	31-JUL-87	14:45:14	0.522	0.522	23.08	11.57	0.0012	0.0019	0.552	0.000
BS87032797 BS87032696	BS87032798	28-JUL-87	09:17:52	0.548	0.548	22.82	12.20	0.0028	0.0031	0.473	0.000
BS87032797 BS87032696	BS87040104	28-JUL-87	08:08:53	0.597	0.597	24.77	11.11	0.0021	0.0032	0.660	0.000
BS87040104 BS87032696	BS87032592	3-AUG-87	13:17:22	0.601	0.601	12.97	7.20	0.0016	0.0028	0.430	0.000

Shot Numbers		Mach Number	DBSQ ABARM	CX CX2 CX4	CNa CNa3 CNa5	CYpa CYpa3	Cma Cma3 Cma5	Cmq Cmq2 Cmq4	Cmpa Cmpa3 Cmpa5	Clp CXm CmaM	Probable Error X(m) Y-Z(m)	Probable Error Angle(deg) Roll(deg)
BS87032490 BS87032797	BS87032798	0.522	23.1 11.6	0.170 1.844 0.00	1.799 0.000 0.00	-1.00 8.00	1.218 1.748 0.0	-0.1 0.0 0.	-0.26 5.54 8.0	-0.0212 0.0000 0.000	0.0012 0.0019	0.5521 0.0000
BS87032797 BS87032696	BS87032798	0.548	22.8 12.2	0.182 0.686 0.00	2.072 -5.743 0.00	-1.00 0.00	1.257 0.000 0.0	-0.1 0.0 0.	-0.67 21.66 0.0	-0.0197 0.0000 0.000	0.0028 0.0031	0.4728 0.0000
BS87032797 BS87032696	BS87040104	0.597	24.8 11.1	0.184 1.310 0.00	1.846 0.000 0.00	-1.00 0.00	1.270 0.000 0.0	-0.3 0.0 0.	-0.21 0.00 0.0	-0.0205 0.0000 0.000	0.0021 0.0032	0.6604 0.0000
BS87040104 BS87032696	BS87032592	0.601	13.0 7.2	0.183 1.832 0.00	1.923 0.000 0.00	-1.00 0.00	1.249 8.504 0.0	-0.1 0.0 0.	-0.55 40.04 0.0	-0.0249 0.0000 0.000	0.0016 0.0028	0.4301 0.0000

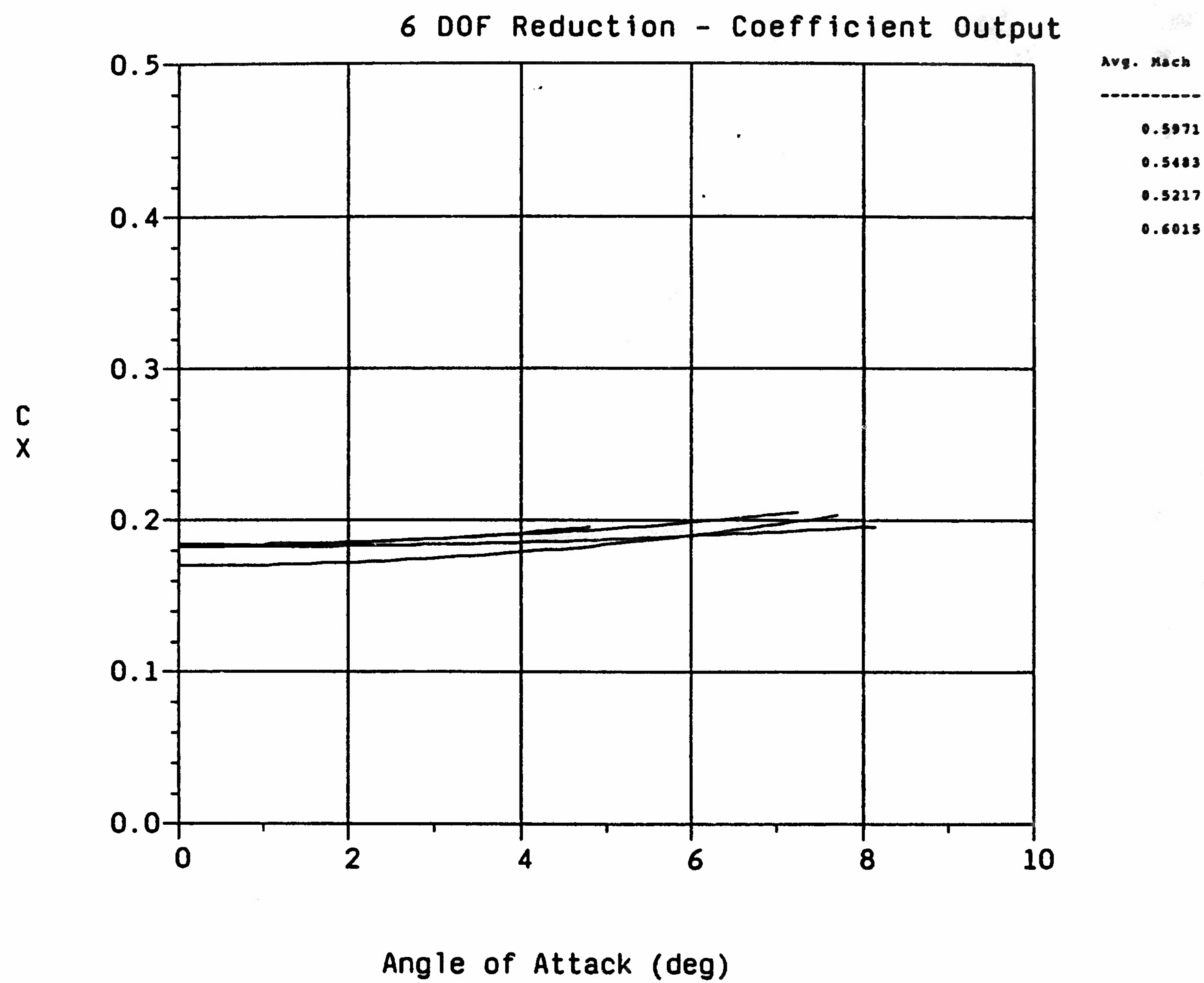


Figure 20. 6 DOF Coefficient Versus Angle of Attack

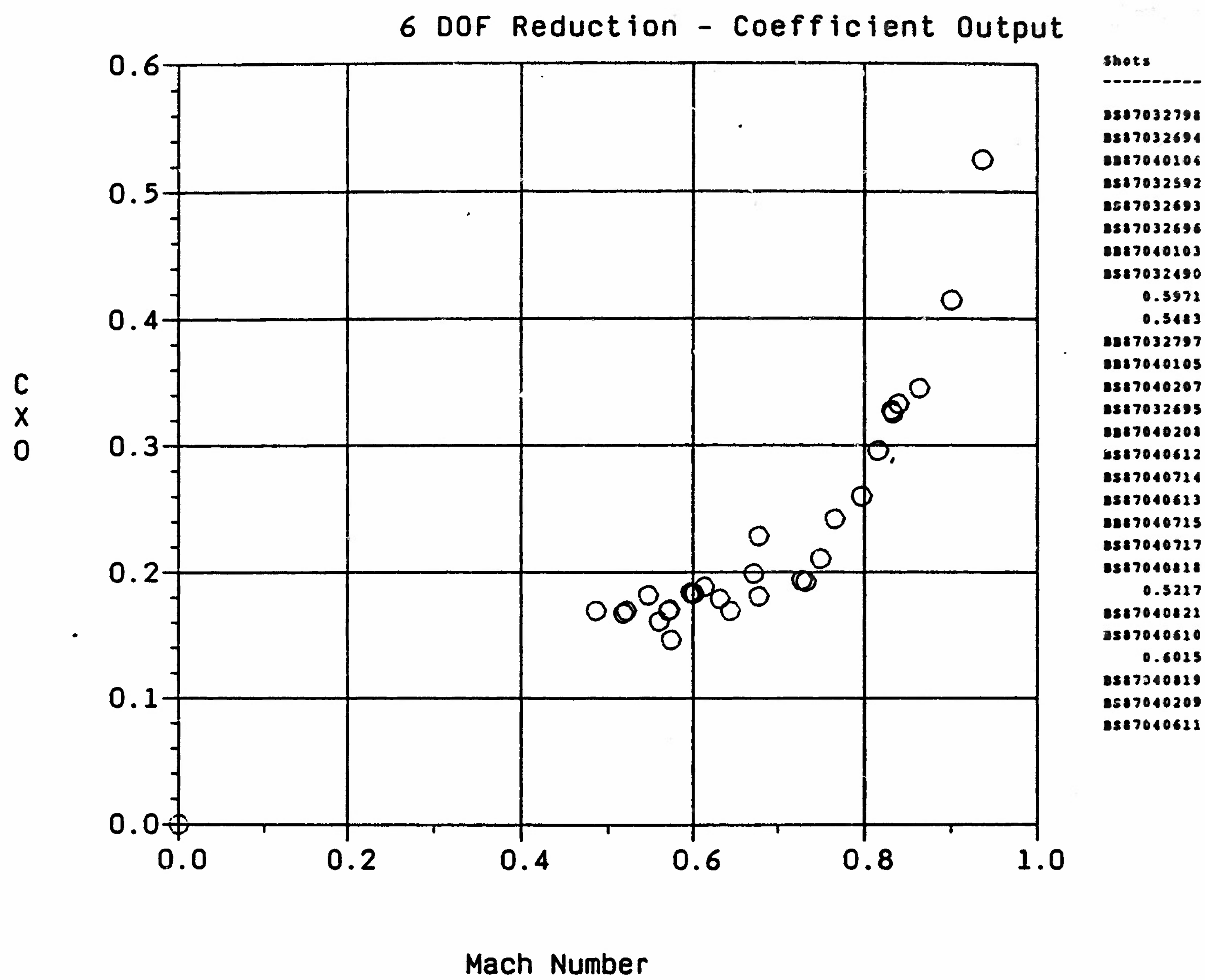


Figure 21. 6 DOF Coefficient Versus Mach Number

From the above menu either motion or residuals may be plotted against the travel down the range. Figure 22 shows a motion plot. Figure 23 shows a residuals plot. For a multiple shot reduction, the data from each shot is available. The program will default to the first shot in the reduction for plotting. Option Twenty enables the user to select other shots for plotting. Option Twenty One enables tabulated data from the motion integration to be printed upon exit from the program.

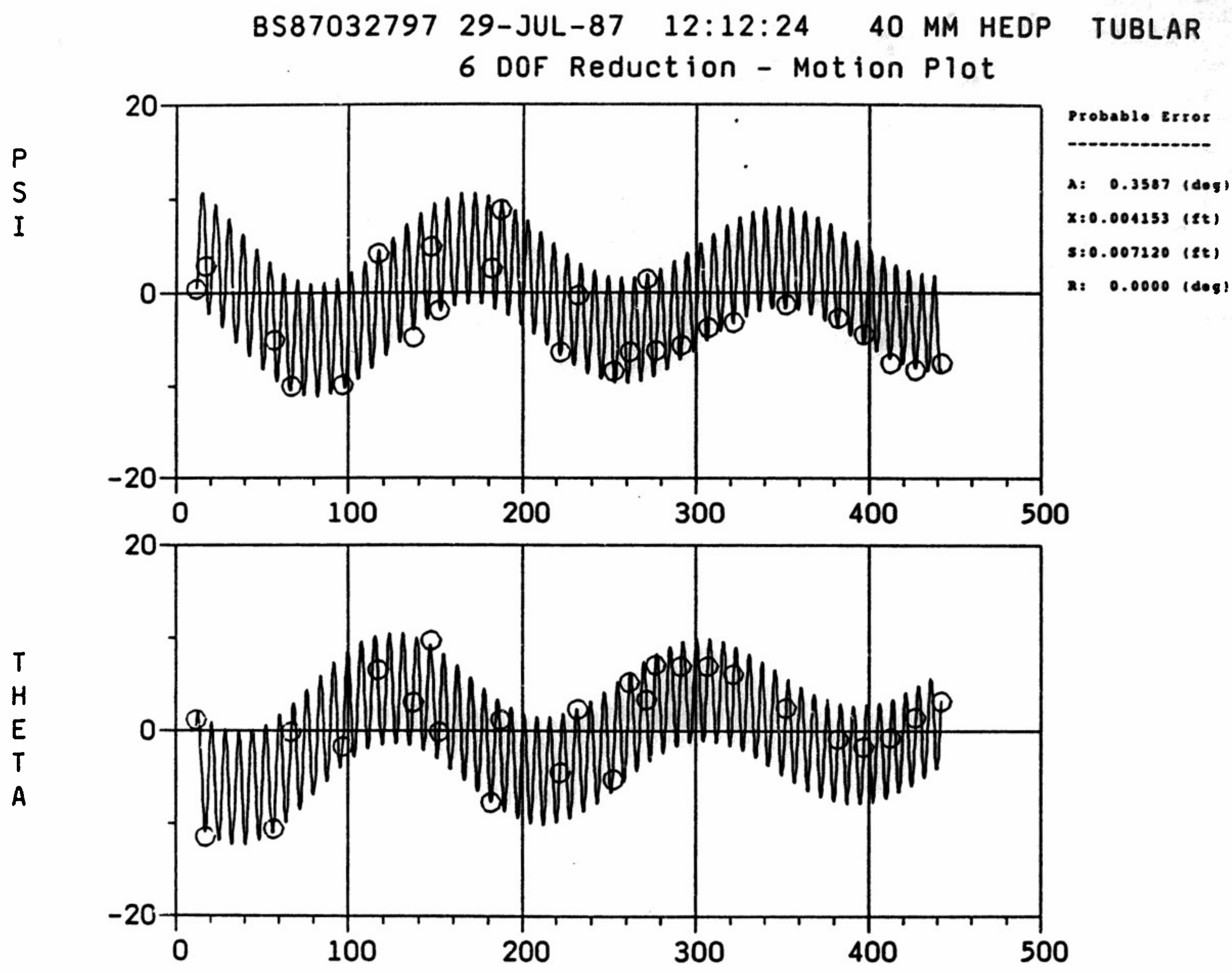


Figure 22. 6 DOF Angular Motion Fit

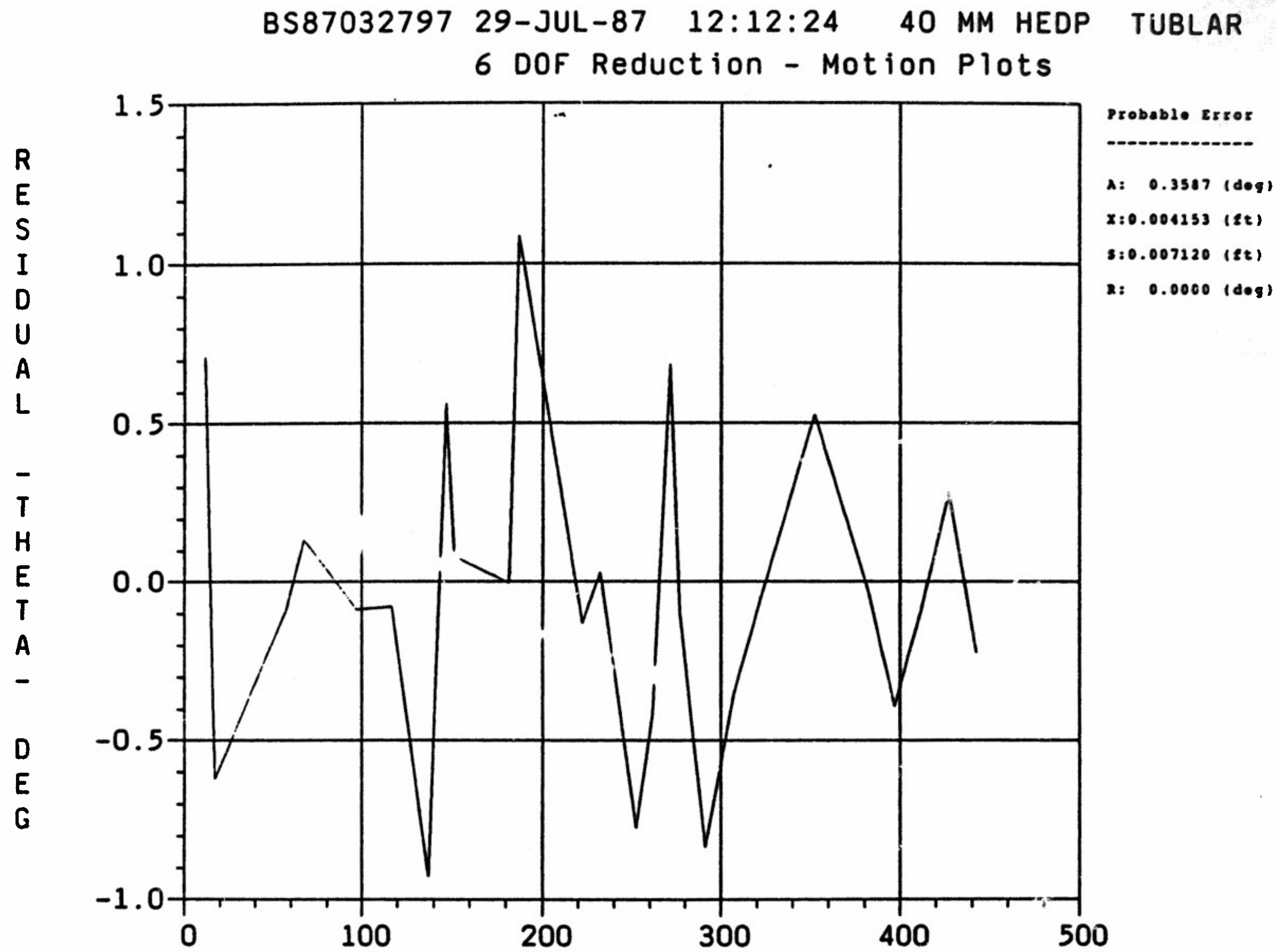


Figure 23. 6 DOF Data Residual

REFERENCES

R.L. Kittyle, J.D. Packard, and G.L. Winchenbach, "Description and Capabilities of the Aeroballistic Research Facility," AFATL-TR-87-08, Air Force Armament Laboratory, Eglin Air Force Base, Florida, 32542-5434, May 1987.

APPENDIX A

TECHNICAL BACKGROUND AND EQUATIONS OF MOTION

APPENDIX A

TECHNICAL BACKGROUND AND EQUATIONS OF MOTION

This section provides the equations of motion contained in the linear theory and 6DOF programs in ARFDAS. These mathematical models are directly correlated to the spark range data resulting in a determination of the aerodynamic coefficients and coefficient derivatives that provide the best fit for the experimental data.

Correlation of the data to the linear theory equations of motion is done using a standard least squares method. This analysis provides for preliminary analysis and screening of the data prior to the 6 DOF. Initial estimates for the initial conditions and coefficients are obtained based on this analysis. A more detailed description and derivation, of the equations, is contained in Reference A-1.

Correlation of the data to the 6 DOF equations of motion is performed using the Maximum Likelihood Method. There are two forms of the dynamic equations available in ARFDAS. Selection of the set of equations depends on the configuration being analyzed. For a configuration with both physical and aerodynamic symmetry, the dynamic equations derived in the fixed plane (nonrotating) coordinate system are used (References A-2 and A-3). When either the physical or aerodynamic model contain asymmetries, the dynamic equations derived in the body fixed (rotating) coordinate system are used (Reference A-4). It should be noted that both 6 DOF programs contain a generalized aerodynamic model. The significant coefficients and derivatives to be determined depend on the type of configuration being analyzed.

Solution of the dynamic equations is performed using a fourth order Runge-Kutta integration. Useful transformation identities between various coordinate systems have been included in this appendix. The sign convention for the fixed plane coordinate system is illustrated in Figures A-1 and A-2. Typical forms of the induced aerodynamic coefficients for a four-fin missile are illustrated in Figures A-3 and A-4.

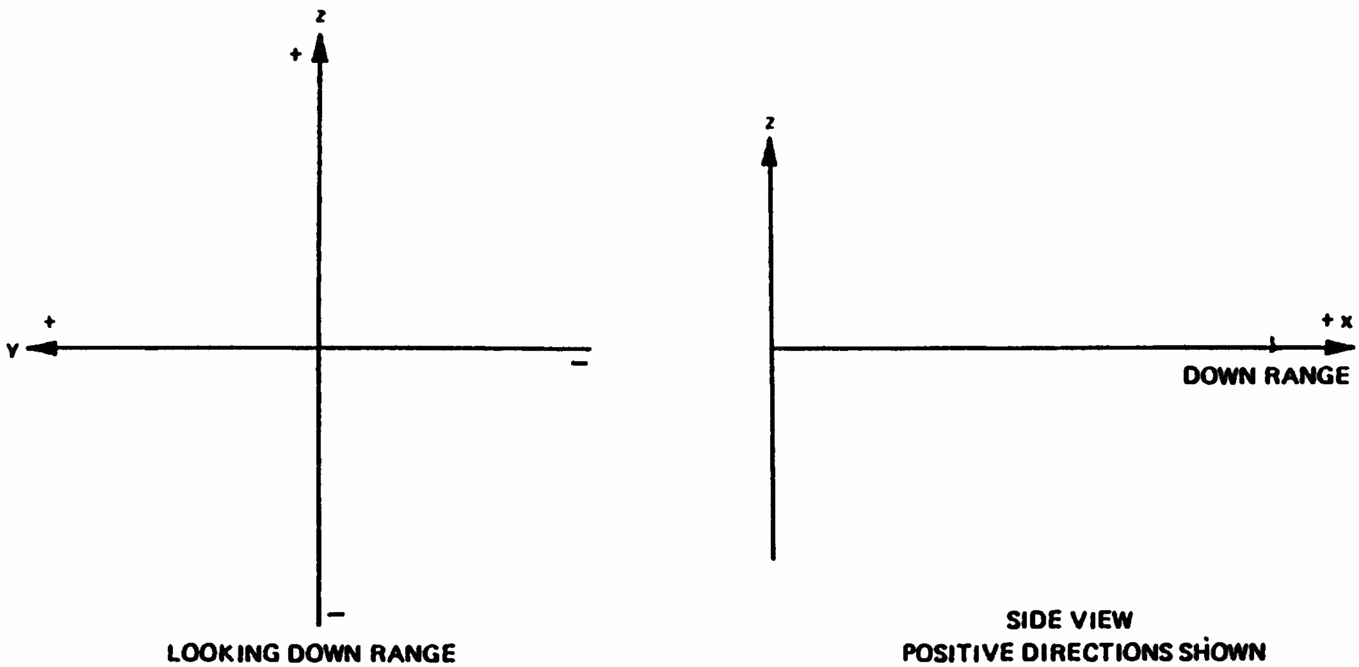


Figure A-1. Coordinate System Fixed Plane (Positions)

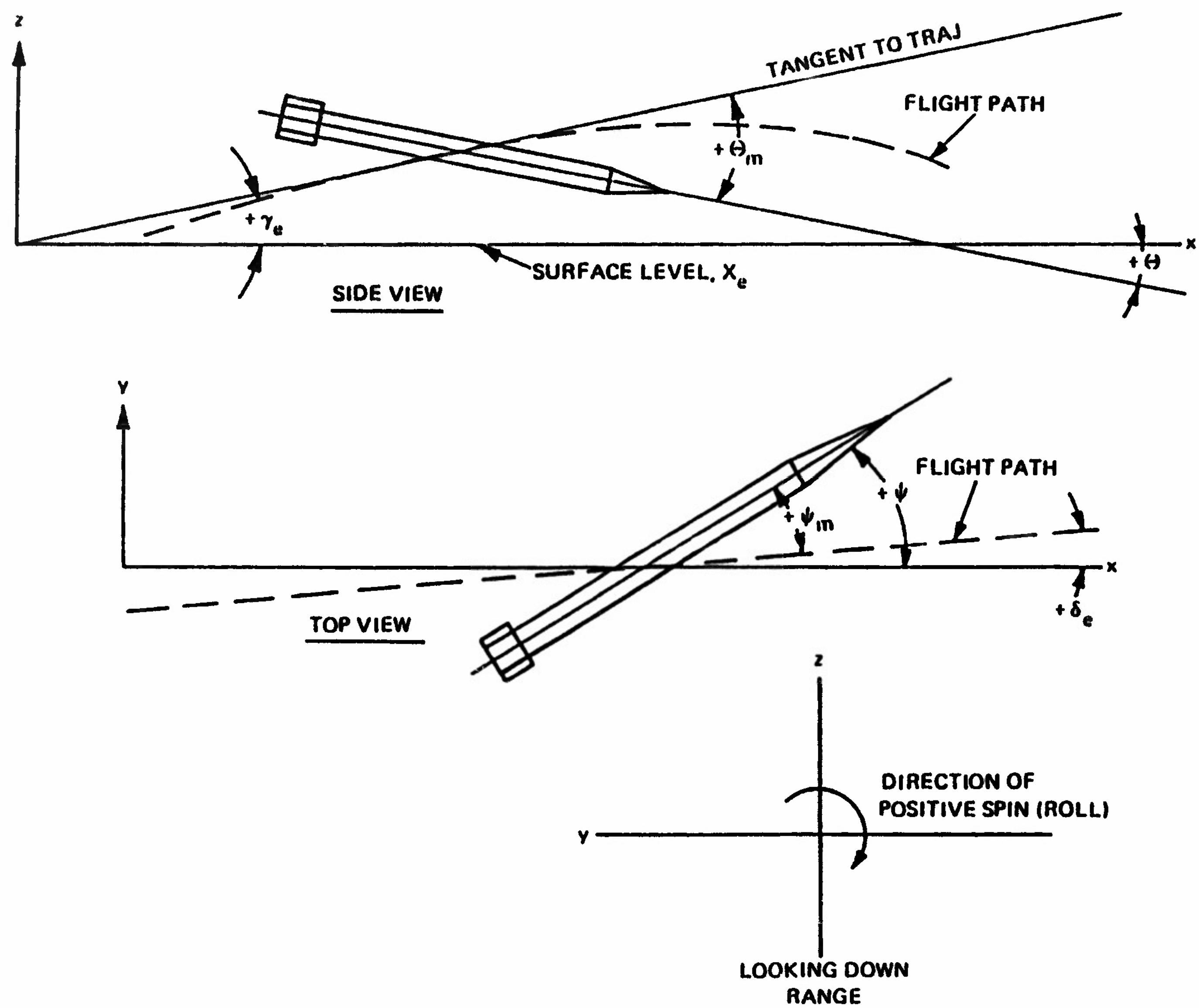
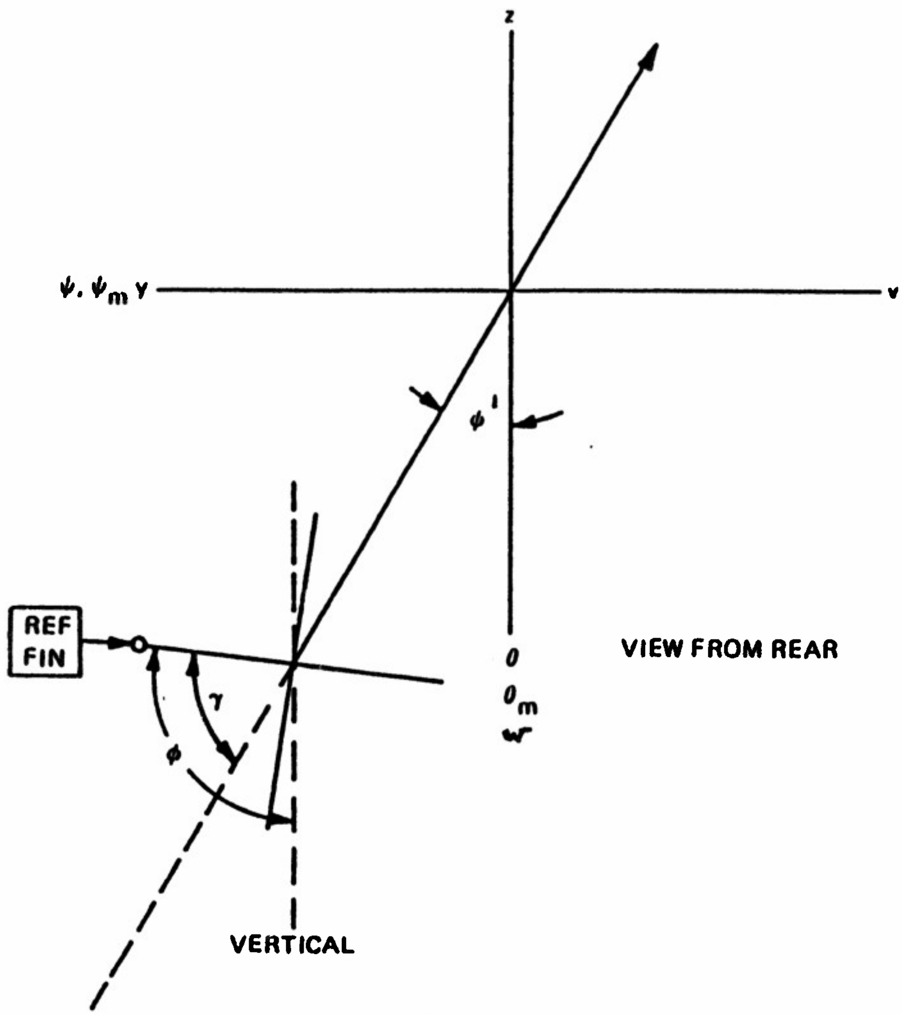


Figure A-2. Coordinate System Fixed Plane (Rotation)

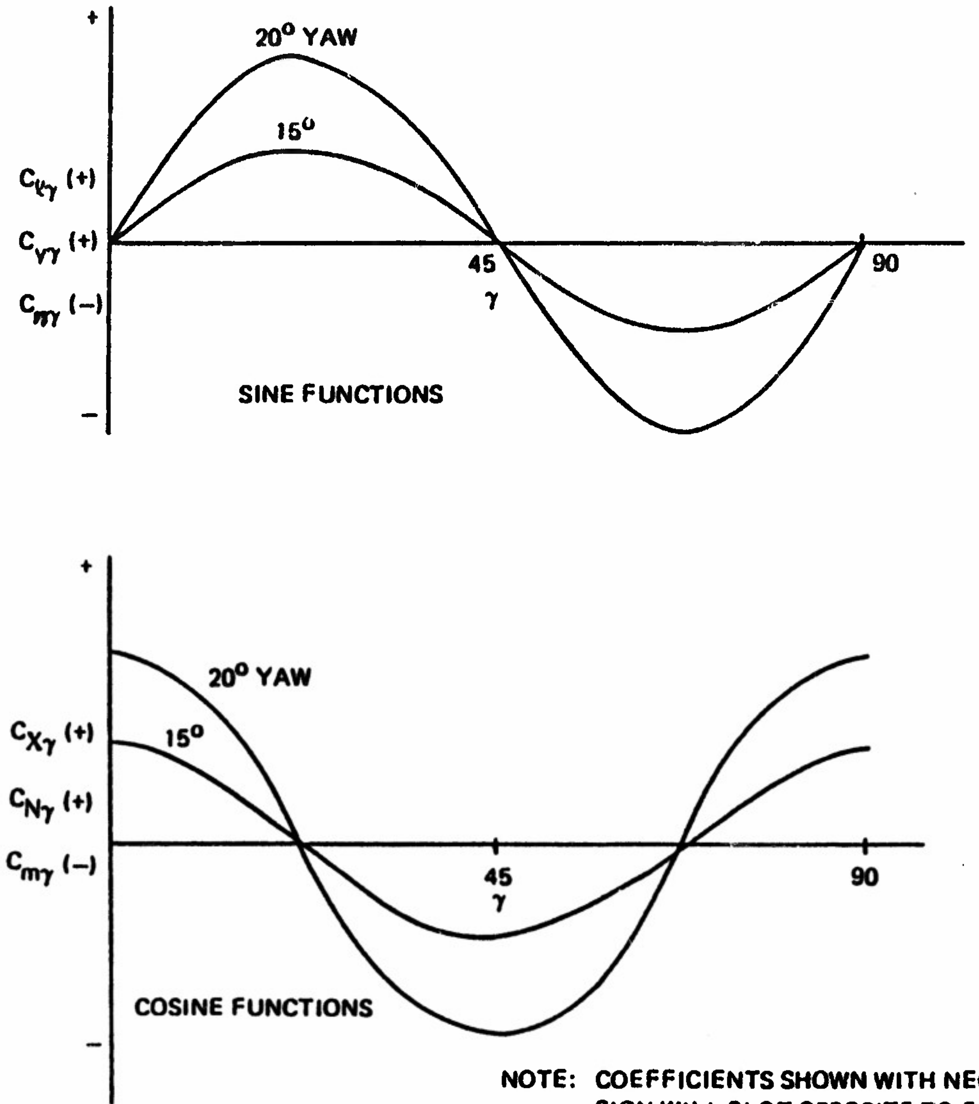


$$\phi^1 = \mathrm{TAN}^{-1}(-v/w)$$
$$\gamma = \phi - \phi^1$$

OR

$$v_b = v\,\mathrm{COS}\,\phi + w\,\mathrm{SIN}\,\phi$$
$$w_b = w\,\mathrm{COS}\,\phi - v\,\mathrm{SIN}\,\phi$$
$$\gamma = \mathrm{TAN}^{-1}\,(v_b/w_b)$$

Figure A-3. Roll Angle Orientations



NOTE: COEFFICIENTS SHOWN WITH NEGATIVE (−) SIGN WILL PLOT OPPOSITE TO EXAMPLE

TYPICAL SIGNS FOR DERIVATIVES ARE:

$C_{\ell\gamma\alpha_2}$ + . $C_{Y\gamma\alpha_3}$ + . $C_{N\gamma\alpha_3}$ +

$C_{x\gamma\alpha_2}$ + . $C_{m\gamma\alpha_3}$ − . $C_{m\gamma\alpha_3}$ −

Figure A-4. Illustrations of Induced Effects (4 Fin Missile)

1. NOMENCLATURE

Physical Properties

A	Area ($\pi d^2/4$)	ft^2
d	Diameter	ft
I_x	Axial moment of inertia	slug-ft^2
I_y	Transverse moment of inertia (y-axis)	slug-ft^2
I_z	Transverse moment of inertia (z-axis)	slug-ft^2
m	Mass	slugs
CG	Center of gravity	% from nose
L	Projectile length	ft
m_c	Mass of ball rotor	slugs
r_x	Distance from CG to CG of ball rotor	ft
r_{yz}	Radial clearance of ball rotor	ft
Subscripts		
r	Reference value	

Range Properties

P	Atmospheric pressure	millibars
T	Temperature	Degrees celcius
RH	Relative humidity	%/100
R_n	Reynolds number	---
M	Mach number	---
a	Speed of sound	ft/sec
ρ	Air density	slugs/ft^3
g	Gravity	32.134 ft/sec^2

Range Properties (continued)

λ_R	Range latitude	30.5 degrees
δ_R	Range azimuth	126.0 degrees
ω_e	Earth rotation rate	
Subscripts		
r	Reference value	

Linear Theory

$d_{1,2,3,4}$	Constants for drag equation
$r_{1,2,3,4}$	Constants for roll equation
K_1	Amplitude nutation vector, degrees
K_2	Amplitude precession vector, degrees
K_3	Amplitude trim vector, degrees
K_4	Amplitude yaw of repose, degrees
ϕ_1	Orientation nutation vector, degrees
ϕ_2	Orientation precession vector, degrees
ϕ_3	Orientation trim vector, degrees
$\dot{\phi}_1$	Angular velocity nutation vector, degrees/ft
$\dot{\phi}_2$	Angular velocity precession vector, degrees/ft
$\dot{\phi}_3$	Angular velocity trim vector, degrees/ft
$\ddot{\phi}_1$	Angular acceleration nutation vector, degrees/ft^2
$\ddot{\phi}_2$	Angular acceleration precession vector, degrees/ft^2
λ_1	Damping factor nutation vector, 1/ft
λ_2	Damping factor precession vector, 1/ft
S_1	Amplitude nutation swerve vector, ft
S_2	Amplitude precession swerve vector, ft
ϕ_{S1}	Orientation nutation swerve vector, degrees
ϕ_{S2}	Orientation precession swerve vector, degrees

Linear Theory (continued)

$zs_{1,2,3}$	Constants for swerve equation (z-plane)
$ys_{1,2,3}$	Constants for swerve equation (y-plane)
x_r	Distance from reference station, ft
x_s	Distance from reference station to midpoint of fit, ft
x_m	Midpoint of fit, ft

Subscripts

m	Evaluated at midpoint of fit

6DOF - Fixed Plane

x,y,z	Missile coordinates (fixed plane) ft
u,v,w	Missile velocities (non-rolling) ft/sec
p,q,r	Missile angular velocities (non-rolling) rad/sec
θ,ψ,ϕ	Missile orientation (fixed plane) radians
a_{cx}, a_{cy}, a_{cz}	Components of coriolis acceleration (fixed plane), ft/sec^2
a_{cu}, a_{cv}, a_{cw}	Components of coriolis acceleration (non-rolling), ft/sec^2
α	Total angle of attack, radians
ε	Sine of the total angle of attack $\left[\frac{(v^2+w^2)}{V^2}\right]^{1/2}$
γ	Aerodynamic roll angle, radians
V	Total missile velocity, ft/sec
F_x, F_y, F_z	Force components (non-rolling), lbs
L, M, N	Moment components (non-rolling), ft-lbs

Superscript

$\cdot$	First derivative with respect to time

6DOF - Body Fixed

x, y, z	Missile coordinates (fixed plane), ft
u_b, v_b, w_b	Missile velocities (rolling), ft/sec
p_b, q_b, r_b	Missile angular velocities (rolling), rad/sec
θ, ψ, ϕ	Missile angular orientation (fixed plane), radians
a_{cx}, a_{cy}, a_{cz}	Components of coriolis acceleration (fixed plane), ft/sec^2
$a_{cub}, a_{cvb}, a_{cwb}$	Components of coriolis acceleration (rolling), ft/sec^2
α	Total angle of attack, radians
ε	Sine of the total angle of attack $\left[\dfrac{v_b^2 + w_b^2}{V^2}\right]^{\frac{1}{2}}$
γ	Aerodynamic roll angle, radians
F_{xb}, F_{yb}, F_{zb}	Force components (rolling), lbs
L_b, M_b, N_b	Moment components (rolling), ft-lbs

Superscripts

$\cdot$	First derivative with respect to time

Aerodynamic Coefficients

C_D	Drag coefficient
C_X	Axial force coefficient
C_N	Normal force coefficient
C_{Yp}	Magnus force coefficient
$C_{X\gamma}$	Induced axial force coefficient
$C_{N\gamma}$	Induced normal force coefficient
$C_{Y\gamma}$	Induced yaw force coefficient
C_Y	Yaw force coefficients
C_Z	Normal force coefficient
C_{Yo}	Trim yaw force coefficient

Aerodynamic Coefficients (continued)

C_{Zo}	Trim normal force coefficient
$C_{N\delta}\delta_A$, $C_{N\delta}\delta_B$	Trim force coefficient components (fixed plane)
C_{Yp}	Magnus force coefficient
$C_{\ell\delta}$	Roll moment coefficient
$C_{\ell p}$	Roll deceleration coefficient
$C_{\ell\gamma}$	Induced roll coefficient
C_m	Pitching moment coefficient
C_n	Yaw moment coefficient
C_{mq}	Pitching damping coefficient
C_{nr}	Yaw damping coefficient
$C_{m\gamma}$	Induced pitching moment coefficient
$C_{n\gamma}$	Induced yaw moment coefficient
C_{mo}	Trim pitch moment coefficient
C_{no}	Trim yaw moment coefficient
$C_{m\delta}\delta_A$, $C_{m\delta}\delta_B$	Trim moment coefficient components (fixed plane)

Let:

$$\alpha = w_b/V$$

$$\beta = v_b/V$$

$$\bar{\alpha}, \varepsilon = \sin^{-1} \left(\frac{v^2 + w^2}{V^2}\right)^{\frac{1}{2}}$$

Subscripts

α_i derivative with respect to α^i

β_i derivative with respect to β^i

$\bar{\alpha}_i$ derivative with respect to ε^i

2. LINEAR THEORY

Linear Theory has the following features:

- o Self start (requires only the precession frequency to be reasonably guessed)
- o Elimination of erroneous data points

The equations shown below define the motion for drag, roll, yaw and swerve.

<u>Drag Analysis</u>

$$t = d_1 + d_2\, x_r + d_3\, x_r^2 + d_4\, x_r^3$$

<u>Roll Analysis</u>

$$\phi = r_1 + r_2 x_r + r_3 x_r^2 + r_4 x_r^3$$

<u>Yaw Analysis</u>

$$\begin{aligned}
\theta_m &= K_1\, e^{\lambda_1 x_r} \cos\left(\phi_1 + \dot{\phi}_1\, x_r + \ddot{\phi}_1\, \frac{x_r^2}{2}\right) \\
&+ K_2\, e^{\lambda_2 x_r} \cos\left(\phi_2 + \dot{\phi}_2\, x_r + \ddot{\phi}_2\, \frac{x_r^2}{2}\right) \\
&+ K_3 \cos\left(\int_1^i \dot{\phi}_3\right) \\
\psi_m &= K_1\, e^{\lambda_1 x_r} \sin\left(\phi_1 + \dot{\phi}_1\, x_r + \ddot{\phi}_1\, \frac{x_r^2}{2}\right) \\
&+ K_2\, e^{\lambda_2 x_r} \sin\left(\phi_2 + \dot{\phi}_2\, x_r + \ddot{\phi}_2\, \frac{x_r^2}{2}\right) \\
&+ K_3 \sin\left(\int_1^i \dot{\phi}_3\right) \\
&+ K_4
\end{aligned}$$

Swerve Analysis

$$y = ys_1 + ys_2 x_r + S_1 e^{\lambda_1 x_r} \sin(\phi_{S1} + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2})$$
$$+ S_2 e^{\lambda_2 x_r} \sin(\phi_{S2} + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2})$$

$$z = zs_1 + zs_2 x_r + zs_3 x_r^2 + S_1 e^{\lambda_1 x_r} \cos(\phi_{S1} + \dot{\phi}_1 x_r + \ddot{\phi}_1 \frac{x_r^2}{2})$$
$$+ S_2 e^{\lambda_2 x_r} \cos(\phi_{S2} + \dot{\phi}_2 x_r + \ddot{\phi}_2 \frac{x_r^2}{2})$$

The reference station for the analysis is Station 1

Let $x_r = x_i - x_1$ (distance from reference)

Definition of Terms

The unknown coefficients which are solved are:

d_1, d_2, d_3, d_4 - drag analysis

r_1, r_2, r_3, r_4 - roll analysis

$K_1, K_2, \lambda_1, \lambda_2, \phi_1, \phi_2, \dot{\phi}_1, \dot{\phi}_2, \ddot{\phi}_1, \ddot{\phi}_2,$

K_3, ϕ_3 - yaw analysis

$S_1, S_2, \phi_{S1}, \phi_{S2}$, $ys_1, ys_2, zs_1, zs_2, zs_3$ - swerve

$\int_1^i \phi_3$ is set equal to the experimental roll position

$$K_4 = \frac{(\dot{\phi}_1 + \ddot{\phi}_1 x_m + \dot{\phi}_2 + \ddot{\phi}_2 x_m)\, g}{(\dot{\phi}_1 + \ddot{\phi}_1 x_m)(\dot{\phi}_2 + \ddot{\phi}_2 x_m)\, V_m^2} \quad \text{(yaw of repose)}$$

$$\theta_m = \theta - \frac{\dot{z}}{\dot{x}}$$

$$\psi_m = \psi + \frac{\dot{y}}{\dot{x}}$$

In order to compute the aerodynamic coefficients, the determined constants are shifted to the midrange distance.

$$x_m = (x_{last} - x_{first}) \cdot \frac{1}{2}$$

$$x_s = x_m - x_r \quad \text{(distance to be shifted)}$$

$$\dot{\phi}_{1m} = \dot{\phi}_1 + \ddot{\phi}_1 x_s$$

$$\dot{\phi}_{2m} = \dot{\phi}_2 + \ddot{\phi}_2 x_s$$

$$\ddot{\phi}_{1m} = \ddot{\phi}_1$$

$$\ddot{\phi}_{2m} = \ddot{\phi}_2$$

$$K_{1m} = K_1 e^{\lambda_1 x_s}$$

$$K_{2m} = K_2 e^{\lambda_2 x_s}$$

$$S_{2m} = S_2 e^{\lambda_2 x_s}$$

$$d_{2m} = d_2 + 2d_3 \cdot x_s + 3d_4 x_s^2$$

$$d_{3m} = d_3 + 3 \cdot d_4 \cdot x_s$$

$$r_{2m} = r_2 + 2r_3 \cdot x_s + 3r_4 x_s^2$$

$$r_{3m} = r_3 + 3 \cdot r_4 \cdot x_s$$

$$C_D \approx \frac{4m}{\rho A} (d_{3m}/d_{2m})$$

$$C_{\ell p_r} \approx 2d\,(r_{3m}/r_{2m} - d_{3m}/d_{2m}) \left(\frac{\pi\rho d^5}{16 I_x}\right)^{-1} \text{- roll fit}$$

$$C_{\ell p_\omega} \approx 2d\,\left(\left(\frac{\dot\phi_{1m} + \dot\phi_{2m}}{\ddot\phi_{1m} + \ddot\phi_{2m}}\right) \frac{1}{2} - d_{3m}/d_{2m}\right) \left(\frac{\pi\rho d^5}{16 I_x}\right)^{-1} \text{- yaw fit}$$

$$C_{m\bar\alpha} \approx \frac{8 I_y\, \dot\phi_{1m} \cdot \dot\phi_{2m}}{\pi\rho d^3}$$

$$C_{m\bar q} \approx \left(\lambda_1 + \lambda_2 + \frac{\rho A C_{N\alpha}}{2m}\right) \frac{16\, I_y}{\pi\rho d^4}$$

$$C_{np\bar\alpha} \approx \left(\lambda_1 \frac{4m}{\rho A} - \frac{md^2}{2I_y} (1 + \tau)\, C_{mq} + C_{N\alpha} (1 - \tau)\right) \frac{I_x}{md^2\, \tau}$$

$$\tau = (\dot\phi_{1m} + \dot\phi_{2m})/(\dot\phi_{1m} - \dot\phi_{2m})$$

$$C_{N\bar\alpha} \approx C_D + \frac{\dot\phi_{2m}\, d\, S_{2m}}{\left(\frac{\pi}{8} \frac{\rho d^3}{m} K_{2m}\right)}$$

No attempt is made during the linear theory analysis to compute $C_{\ell\delta}$ or $C_{Yp\alpha}$ as these will be determined in the 6 DOF analysis. These coefficients are not necessary as estimates for the 6 DOF analysis.

3. SIX DEGREE OF FREEDOM

The data analysis system currently consists of two 6 DOF programs.

- o Fixed plane 6 DOF for symmetric missiles or projectiles including induced forces and moments.
- o Body fixed 6 DOF for configurations such as airplanes or symmetric missiles with or without mass asymmetries.

Both 6 DOF programs can reduce (analyze) up to five sets of experimental data (shots) simultaneously and determine the set of aerodynamic coefficients which best fit all the data.

The equations of motion, force and moment summations, and aerodynamic coefficients will be discussed in this section for each 6 DOF program individually.

6 DOF Fixed Plane

The equations of motion have been derived in a fixed plane coordinate system. The X-axis points downrange, the Y-axis points to the left looking downrange and the Z-axis points up. Coriolis effects have been accounted for.

$$\dot{x} = u \cos\theta \cos\psi - v \sin\psi + w \sin\theta \cos\psi$$

$$\dot{y} = u \cos\theta \sin\psi + v \cos\psi + w \sin\theta \sin\psi$$

$$\dot{z} = -u \sin\theta + w \cos\theta$$

$$a_{cx} = -2\omega_e (\dot{y} \sin\lambda_R + \dot{z} \cos\lambda_R \sin\delta_R)$$

$$a_{cy} = 2\omega_e (\dot{x} \sin\lambda_R - \dot{z} \cos\lambda_R \cos\delta_R)$$

$$a_{cz} = 2\omega_e (\dot{x} \cos\lambda_R \sin\delta_R + \dot{y} \cos\lambda_R \cos\delta_R)$$

$$a_{cu} = \dot{a}_{cx} \cos\theta \cos\psi + a_{cy} \cos\theta \sin\psi - a_{cz} \sin\theta$$

$$a_{cv} = -a_{cx} \sin\psi + a_{cy} \cos\psi$$

$$a_{cw} = a_{cx} \sin\theta \cos\psi + a_{cy} \sin\theta \sin\psi + a_{cz} \cos\theta$$

$$\dot{\theta} = q$$

$$\dot{\psi} = r/\cos\theta$$

$$\dot{\phi} = p + r\tan\theta$$

$$\dot{u} = g \sin\theta - qw + rv - a_{cu} + F_x/m$$

$$\dot{v} = -ru - rw\tan\theta - a_{cv} + F_y/m$$

$$\dot{w} = -g \cos\theta + rv \tan\theta + qu - a_{cw} + F_z/m$$

$$\dot{p} = L/I_x$$

$$\dot{q} = -r^2 \tan\theta - I_x/I_y \, rp + M/I_y$$

$$\dot{r} = +qr\tan\theta + I_x/I_y \, qp + N/I_y$$

Aerodynamic Model

The aerodynamic forces and moments of symmetric spin stabilized projectile and fin stabilized missiles are shown below as they are currently modeled in the MIMFXPL program. For the fin stabilized case, the analysis includes the induced forces and moments. At present, the coefficients are assumed to be functions of Mach number, the sine of the total angle of attack, and the aerodynamic roll angle.

Summation of Forces and Moments

$$F_x = -\bar{q} \, A \, \bar{C}_X$$

$$F_y = \bar{q} \, A \, [-\bar{C}_{N\alpha} \frac{v}{V} + \frac{pd}{2V} \bar{C}_{Yp\alpha} \frac{w}{V} + \bar{C}_{Y\gamma\alpha} \frac{w}{V}$$

$$+\bar{C}_{N\delta}\delta_A \sin\phi - \bar{C}_{N\delta}\delta_B \cos\phi \,]$$

$$F_z = \bar{q} \, A \, [-\bar{C}_{N\alpha} \frac{w}{V} - \frac{pd}{2V} \bar{C}_{Yp\alpha} \frac{v}{V} - \bar{C}_{Y\gamma\alpha} \frac{v}{V}$$

$$-\bar{C}_{N\delta}\delta_A \cos\phi - \bar{C}_{N\delta}\delta_B \sin\phi \,]$$

$$L = \bar{q} \, Ad \, [\, \frac{pd}{2V} \bar{C}_{\ell p} + \bar{C}_{\ell} \,]$$

$$M = \bar{q} \, Ad \, [\bar{C}_{m\alpha} \frac{w}{V} + \frac{qd}{2V} \bar{C}_{mq} + \frac{pd}{2V} \bar{C}_{np\alpha} \frac{v}{V}$$

$$+\bar{C}_{n\gamma\alpha} \frac{v}{V} + \bar{C}_{m\delta}\delta_A \cos\phi - \bar{C}_{m\delta}\delta_B \sin\phi + RMQ \,]$$

$$N = \bar{q}\,Ad\,[-\bar{C}_{m\alpha}\frac{v}{V} + \frac{rd}{2V}\bar{C}_{mq} + \frac{pd}{2V}\bar{C}_{np\alpha}\frac{w}{V}$$

$$+ \bar{C}_{n\gamma\alpha}\frac{w}{V} + C_{m\delta}\delta_A \sin\phi + C_{m\delta}\delta_B \cos\phi + RNQ\,]$$

Aerodynamic Coefficient Expansions

$$\bar{C}_X = C_{Xo} + C_{X\bar{\alpha}_2}\varepsilon^2 + C_{X\bar{\alpha}_4}\varepsilon^4 + C_{Xm}(M_1 - M_r) + C_{X\gamma\bar{\alpha}_2}\varepsilon^2 \cos N\gamma$$

$$\bar{C}_{N\alpha} = C_{N\bar{\alpha}} + C_{N\bar{\alpha}_3}\varepsilon^2 + C_{N\bar{\alpha}_5}\varepsilon^4 + C_{N\gamma\bar{\alpha}_3}\varepsilon^2 \cos N\gamma + C_{N\bar{\alpha}m}(M_1 - M_r)$$

$$\bar{C}_{N\delta}\delta_A = C_{N\delta}\delta_A$$

$$\bar{C}_{N\delta}\delta_B = C_{N\delta}\delta_B$$

$$\bar{C}_{Yp\alpha} = C_{Yp\bar{\alpha}} + C_{Yp\bar{\alpha}_3}\varepsilon^2$$

$$\bar{C}_{Y\gamma\alpha} = C_{Y\gamma\bar{\alpha}_3}\varepsilon^2 \sin N\gamma$$

$$\bar{C}_{\ell p} = C_{\ell p} + C_{\ell p\bar{\alpha}_2}\varepsilon^2 + C_{\ell pm}(M_1 - M_r)$$

$$\bar{C}_{\ell} = \bar{C}_{\ell\delta}\delta + C_{\ell\gamma\bar{\alpha}_2}\varepsilon^2 \sin N\gamma$$

$$\bar{C}_{m\alpha} = C_{m\bar{\alpha}} + C_{m\bar{\alpha}_3}\varepsilon^2 + C_{m\bar{\alpha}_5}\varepsilon^4 + C_{m\alpha}(M_1 - M_r) + C_{m\gamma\bar{\alpha}_3}\varepsilon^2 \cos N\gamma$$
$$+ \bar{C}_{N\bar{\alpha}}(CG - CG_r) + C_{m\gamma\bar{\alpha}_5}\varepsilon^4 \cos N\gamma$$

$$\bar{C}_{mq} = C_{m\bar{q}} + C_{m\bar{q}\bar{\alpha}_2}\varepsilon^2 + C_{m\bar{q}\bar{\alpha}_4}\varepsilon^4$$

$$\bar{C}_{np\alpha} = C_{np\bar{\alpha}} + C_{np\bar{\alpha}_3}\varepsilon^2 + C_{np\bar{\alpha}_5}\varepsilon^4 + C_{np\bar{\alpha}_7}\varepsilon^6$$

$$\bar{C}_{n\gamma\alpha} = C_{n\gamma\bar{\alpha}_3} \epsilon^2 \sin N\gamma + C_{n\gamma\bar{\alpha}_5} \epsilon^4 \sin N\gamma$$

$$\bar{C}_{m\delta}\,\delta_A = C_{m\delta}\,\delta_A$$

$$\bar{C}_{m\delta}\,\delta_B = C_{m\delta}\,\delta_B$$

The following terms represent nonplanar damping variations.

$$RMQ = C_{mq2N} \left[\left(\frac{qd}{2V}\right) \left(\frac{w^2}{V^2}\right) - \left(\frac{rd}{2V}\right) \left(\frac{vw}{V^2}\right) \right] + C_{nq2N} \left[\left(\frac{qd}{2V}\right) \left(\frac{v^2}{V^2}\right) + \left(\frac{rd}{2V}\right) \left(\frac{vw}{V^2}\right) \right]$$

$$RNQ = C_{mq2N} \left[\left(\frac{rd}{2V}\right) \left(\frac{v^2}{V^2}\right) - \left(\frac{qd}{2V}\right) \left(\frac{vw}{V^2}\right) \right] + C_{nr2N} \left[\left(\frac{rd}{2V}\right) \left(\frac{w^2}{V^2}\right) + \left(\frac{qd}{2V}\right) \left(\frac{vw}{V^2}\right) \right]$$

The aerodynamic roll angle is computed by transforming the fixed plane velocities into the rolling body coordinate system as follows:

$$v_b = v \cos\phi + w \sin\phi$$

$$w_b = -v \sin\phi + w \cos\phi$$

$$\gamma = \tan^{-1} (v_b/w_b)$$

<u>6 DOF Body Fixed</u>

Since the aerodynamic forces and moments are defined in a body-fixed coordinate system, the equations of motion were derived with respect to a rotating coordinate system. This coordinate system is defined with the x-axis aligned with the longitudinal axis of the missile and points out the nose, the y-axis points out the left wing, and the z-axis points up with respect to the body. The body-fixed coordinate system is rigidly attached to the missile and rotates with the missile about the x-axis. The inertial frame of reference is the Earth. It is assumed that the Earth is fixed in space and flat. Coriolis effects are included in the equations.

$$\dot{x} = u_b \cos\theta \cos\psi + v_b (\sin\theta \sin\phi \cos\psi - \cos\phi \sin\psi) + w_b (\sin\theta \cos\phi \cos\psi + \sin\phi \sin\psi)$$

$$\dot{y} = u_b \cos\theta \sin\psi + v_b (\sin\theta \sin\phi \sin\psi + \cos\phi \cos\psi) + w_b (\sin\theta \cos\phi \sin\psi - \sin\phi \cos\psi)$$

$$\dot{z} = -u_b \sin\theta + v_b \cos\theta \sin\phi + w_b \cos\theta \cos\phi$$

$$a_{cx} = -2\omega_e (\dot{y} \sin\lambda_R + \dot{z} \cos\lambda_R \sin\delta_R)$$

$$a_{cy} = 2\omega_e (\dot{x} \sin\lambda_R - \dot{z} \cos\lambda_R \cos\delta_R)$$

$$a_{cz} = 2\omega_e (\dot{x} \cos\lambda_R \sin\delta_R + \dot{y} \cos\lambda_R \cos\delta_R)$$

$$a_{cub} = a_{cx} \cos\theta \cos\psi + a_{cy} \cos\theta \sin\psi - a_{cz} \sin\theta$$

$$a_{cvb} = a_{cx} (\sin\theta \sin\phi \cos\psi - \cos\phi \sin\psi) + a_{cy} (\sin\theta \sin\phi \sin\psi + \cos\phi \cos\psi) + a_{cz} (\sin\phi \cos\theta)$$

$$a_{cwb} = a_{cx} (\sin\theta \cos\phi \cos\psi + \sin\phi \sin\psi) + a_{cy} (\sin\theta \cos\phi \sin\psi - \sin\phi \cos\psi) + a_{cz} (\cos\phi \cos\theta)$$

$$\dot{\theta} = q_b \cos\phi - r_b \sin\phi$$

$$\dot{\psi} = (q_b \sin\phi + r_b \cos\phi)/\cos\theta$$

$$\dot{\phi} = p_b + \tan\theta \, (q_b \sin\phi + r_b \cos\phi)$$

$$\dot{u}_b = r_b v_b - q_b w_b - a_{cub} + F_{xb}/m + g \sin\theta$$

$$\dot{v}_b = p_b w_b - r_b u_b - a_{cvb} + F_{yb}/m - g \sin\phi \cos\theta$$

$$\dot{w}_b = q_b u_b - p_b v_b - a_{cwb} + F_{zb}/m - g \cos\phi \cos\theta$$

$$\dot{p}_b = \frac{I_y\, L_b + I_{xy}\, M_b - (I_x + I_y - I_z)\, I_{xy} p_b r_b + (I_{xy}^{\ 2} + I_y\, (I_y - I_z))\, q_b r_b}{(I_x\, I_y - I_{xy}^{\ 2})}$$

$$\dot{q}_b = \frac{I_x\, M_b + I_{xy}\, L_b + (I_x + I_y - I_z)\, I_{xy} q_b r_b + (I_x (I_z - I_x) - I_{xy}^{\ 2})\, p_b r_b}{(I_x\, I_y - I_{xy}^{\ 2})}$$

$$\dot{r}_b = \frac{N_b + I_{xy}\, (p_b^2 - q_b^2) + (I_x - I_y)\, p_b q_b}{I_z}$$

Aerodynamic Model

The aerodynamic forces and moments currently modeled in the body fixed program are given below. Coefficients are assumed to be functions of Mach number, the sine of the pitch and yaw angles, or the total angle of attack and the aerodynamic roll angle.

Summation of Forces and Moments

$$F_{xb} = - \bar{q}\ A\ \bar{C}_X$$

$$F_{yb} = \bar{q}\ A\ (- \bar{C}_{Yo} - \bar{C}_{Y\beta} \frac{v_b}{V} + \bar{C}_{Y\gamma\alpha} \frac{w_b}{V} + \bar{C}_{Yp\alpha} \frac{p_b d}{2V} \frac{w_b}{V})$$

$$F_{zb} = \bar{q}\ A\ (- \bar{C}_{Zo} - \bar{C}_{Z\alpha} \frac{w_b}{V} - \bar{C}_{Y\gamma\alpha} \frac{v_b}{V} - \bar{C}_{Yp\alpha} \frac{p_b d}{2V} \frac{v_b}{V})$$

$$L_b = \bar{q}\ A\ d\ (\frac{p_b d}{2V} \bar{C}_{\ell p} + \bar{C}_{\ell})$$

$$M_b = \bar{q}\ A\ d\ (\bar{C}_{mo} + \bar{C}_{m\alpha} \frac{w_b}{V} + \bar{C}_{mq} \frac{q_b d}{2V} + \bar{C}_{np\alpha} \frac{p_b d}{2V} \frac{v_b}{V} + \bar{C}_{n\gamma\alpha} \frac{v_b}{V})$$

$$N_b = \bar{q}\ A\ d\ (+ \bar{C}_{no} - \bar{C}_{n\beta} \frac{v_b}{V} + \bar{C}_{nr} \frac{r_b d}{2V} + \bar{C}_{np\alpha} \frac{p_b d}{2V} \frac{w_b}{V} + \bar{C}_{n\gamma\alpha} \frac{w_b}{V}$$

Aerodynamic Coefficient Expansions

$$\bar{C}_X = C_{Xo} + C_{X\alpha}\left(\frac{w_b}{V}\right) + C_{X\alpha_2}\left(\frac{w_b}{V}\right)^2 + C_{X\beta_2}\left(\frac{v_b}{V}\right)^2 + C_{Xm}(M_i - M_r) + C_{X\bar{\alpha}_2}\,\varepsilon^2$$

$$\bar{C}_{Yo} = C_{Yo}$$

$$\bar{C}_{Zo} = C_{Zo}$$

$$\bar{C}_{Y\beta} = -C_{Y\beta} - C_{Y\beta_3}\left(\frac{v_b}{V}\right)^2 + C_{N\bar{\alpha}} + C_{N\bar{\alpha}_3}\,\varepsilon^2 + C_{N\gamma\bar{\alpha}_3}\,\varepsilon^2 \cos N\gamma$$

$$\bar{C}_{Z\alpha} = C_{Z\alpha} + C_{Z\alpha_2}\left(\frac{w_b}{V}\right) + C_{Z\alpha_3}\left(\frac{w_b}{V}\right)^2 + C_{N\bar{\alpha}} + C_{N\bar{\alpha}_3}\,\varepsilon^2 + C_{N\gamma\bar{\alpha}_3}\,\varepsilon^2 \cos N\gamma$$

$$\bar{C}_{Y\gamma\alpha} = C_{Y\gamma\bar{\alpha}_3}\,\varepsilon^2 \sin N\gamma$$

$$\bar{C}_{Yp\alpha} = C_{Yp\alpha}$$

$$\bar{C}_{\ell p} = C_{\ell p}$$

$$\bar{C}_{\ell} = C_{\ell\delta}\,\delta + C_{\ell\gamma\alpha_2}\,\varepsilon^2 \sin N\gamma + C_{\ell\beta}\left(\frac{v_b}{V}\right)$$

$$\bar{C}_{mo} = C_{mo}$$

$$\bar{C}_{no} = C_{no}$$

$$\bar{C}_{m\alpha} = C_{m\alpha} + C_{m\alpha 2}\left(\frac{w_b}{V}\right) + C_{m\alpha_3}\left(\frac{w_b}{V}\right)^2 + C_{m\bar{\alpha}} + C_{m\bar{\alpha}_3}\,\varepsilon^2 + C_{m\gamma\bar{\alpha}_3}\,\varepsilon^2 \cos N\gamma + \bar{C}_{Z\alpha}(CG - CG_r)$$

$$\bar{C}_{mq} = C_{mq} + C_{mq\alpha_2}\left(\frac{w_b}{V}\right)^2 + C_{m\bar{q}} + C_{m\bar{q}\bar{\alpha}_2}\,\varepsilon^2$$

$$\bar{C}_{n\beta} = -C_{n\beta} - C_{n\beta_3} \left(\frac{v_b}{V}\right)^2 + C_{m\bar{\alpha}} + C_{m\bar{\alpha}_3} \epsilon^2 + C_{m\gamma\bar{\alpha}_3} \epsilon^2 \cos N \gamma$$

$$+ \bar{C}_{Y\beta} (CG - CG_r)$$

$$\bar{C}_{nr} = C_{nr} + C_{nr\beta_2} \left(\frac{v_b}{V}\right)^2 + C_{m\bar{q}} + C_{m\bar{q}\bar{\alpha}_2} \epsilon^2$$

$$\bar{C}_{n\gamma\alpha} = C_{n\gamma\alpha_3} \epsilon^2 \sin N \gamma$$

$$\bar{C}_{np\alpha} = C_{np\alpha}$$

The aerodynamic roll angle is computed as follows:

$$\gamma = \tan^{-1} (v_b/w_b)$$

Transformations (Fixed Plane)

Missile to Earth

$$\dot{x} = u \cos\theta \cos\psi - v \sin\psi + w \sin\theta \cos\psi$$

$$\dot{y} = u \cos\theta \sin\psi + v \cos\psi + w \sin\theta \sin\psi$$

$$\dot{z} = -u \sin\theta + w \cos\theta$$

Earth to Missile

$$u = \dot{x} \cos\theta \cos\psi + \dot{y} \cos\theta \sin\psi - \dot{z} \sin\theta$$

$$v = -\dot{x} \sin\psi + \dot{y} \cos\psi$$

$$w = \dot{x} \sin\theta \cos\psi + \dot{y} \sin\theta \sin\psi + \dot{z} \cos\theta$$

Transformations (Body Fixed)

Missile to Earth

$$\dot{x} = u_b \cos\theta \cos\psi + v_b (\sin\theta \sin\phi \cos\psi - \cos\phi \sin\psi) + w_b (\sin\theta \cos\phi \cos\psi + \sin\phi \sin\psi)$$

$$\dot{y} = u_b \cos\theta \sin\psi + v_b (\sin\theta \sin\phi \sin\psi + \cos\phi \cos\psi) + w_b (\sin\theta \cos\phi \sin\psi - \sin\phi \cos\psi)$$

$$\dot{z} = -u_b \sin\theta + v_b \cos\theta \sin\phi + w_b \cos\theta \cos\phi$$

Transformations (Body Fixed)

Earth to Missile

$$u_b = \dot{x}\cos\theta\cos\psi + \dot{y}\cos\theta\sin\psi - \dot{z}\sin\theta$$

$$\begin{aligned} v_b = {} & \dot{x}(\sin\theta\sin\phi\cos\psi - \cos\phi\sin\psi) \\ & + \dot{y}(\sin\theta\sin\phi\sin\psi + \cos\phi\cos\psi) \\ & + \dot{z}(\cos\theta\sin\phi) \end{aligned}$$

$$\begin{aligned} w_b = {} & \dot{x}(\sin\theta\cos\phi\cos\psi + \sin\phi\sin\psi) \\ & + \dot{y}(\sin\theta\cos\phi\sin\psi - \sin\phi\cos\psi) \\ & + \dot{z}(\cos\theta\cos\phi) \end{aligned}$$

Transformations

Body Fixed to Fixed Plane

$$u = u_b$$

$$v = v_b \cos\phi - w_b \sin\phi$$

$$w = v_b \sin\phi + w_b \cos\phi$$

$$p = p_b$$

$$q = q_b \cos\phi - r_b \sin\phi$$

$$r = q_b \sin\phi + r_b \cos\phi$$

Fixed Plane to Body Fixed

$$u_b = u$$

$$v_b = v \cos\phi + w \sin\phi$$

$$w_b = -v \sin\phi + w \cos\phi$$

$$p_b = p$$

$$q_b = q \cos\phi + r \sin\phi$$

$$r_b = -q \sin\phi + r \cos\phi$$

Direction Cosines to Fixed Plane

$$\theta = -\sin^{-1}(n_e)$$

$$\psi = \sin^{-1}(m_e/(m_e^2 + p_e^2)^{\frac{1}{2}})$$

Angular Identities

Missile Angles

$$\sin \bar{\alpha}_m = \sqrt{\sin^2 \psi_m + \cos^2 \psi_m \sin^2 \theta_m}$$

$$\sin \theta_m = \sin \chi_m / \cos \psi_m$$

$$\sin \theta_m = \sin \alpha_m$$

$$\sin \psi_m = - \sin \beta_m \cos \chi_m$$

$$\tan \beta_m = - \tan \psi_m / \cos \theta_m$$

Missile Angles - Earth Angles

$$\theta = \theta_m - \sin^{-1} [\sin \gamma_e / \cos \psi_m]$$

$$\psi = \sin^{-1} [\sin \psi_m / \cos \gamma_e] + \delta_e$$

Angular Identities

Earth Angles

$$\tan \theta = \tan \chi \cos \psi$$

Missile Velocities - Missile Angles

$$v = - V \sin \psi_m$$

$$w = V \cos \psi_m \sin \theta_m$$

$$u = V \cos \psi_m \cos \theta_m$$

Missile Angle - Velocity Relationship

ANGLE	SINE	COSINE	TANGENT
χ_m	$\frac{w}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{u^2 + v^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{w}{\sqrt{u^2 + v^2}}$
ψ_m	$\frac{-v}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{u^2 + w^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{-v}{\sqrt{u^2 + w^2}}$
θ_m	$\frac{w}{\sqrt{u^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + w^2}}$	$\frac{w}{u}$
α_m	$\frac{w}{\sqrt{u^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + w^2}}$	$\frac{w}{u}$
β_m	$\frac{v}{\sqrt{u^2 + v^2}}$	$\frac{u}{\sqrt{u^2 + v^2}}$	$\frac{v}{u}$
$\bar{\alpha}_m$	$\frac{\sqrt{v^2 + w^2}}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{u}{\sqrt{u^2 + v^2 + w^2}}$	$\frac{\sqrt{v^2 + w^2}}{u}$

Trajectory Angle - Velocity Relationships

ANGLE	SINE	COSINE	TANGENT
γ_e	$\dfrac{\dot{z}}{V}$	$\dfrac{(\dot{x}^2 + \dot{y}^2)^{1/2}}{V}$	$\dfrac{\dot{z}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$
δ_e	$\dfrac{\dot{y}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$	$\dfrac{\dot{x}}{(\dot{x}^2 + \dot{y}^2)^{1/2}}$	$\dfrac{\dot{y}}{\dot{x}}$

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APPENDIX B

6 DOF COEFFICIENT INPUT LINE NUMBERS AND ANALYSIS INDEX NUMBERS

APPENDIX B

6 DOF Coefficient Input Line Numbers
and
Analysis Index Numbers

Each coefficient in the 6 DOF programs has an associated input line number and analysis index number. The input line number is used to specify initial conditions at fit flags. These numbers are always sequential for the table currently being displayed. Since initial fit options are different from subsequent fit options, there will be different menus for each. The same is true for fixed plane and body fixed coordinate systems.

Within the analysis program there is one vector of variables for all the coefficients. These numbers are used within the 6 DOF program for specifying parameters and fit flags. A different vector exists for fixed plane and body fixed coordinate systems.

The following pages will define the parameters available within the 6 DOF program and the associated line and index numbers:

1. FIXED PLANE LINE NUMBERS

For each shot in the analysis (up to 5), a menu of aerodynamic coefficients will be displayed. For the last shot in the fit, a menu of physical parameters is displayed. For each shot fit, menus for both aerodynamic coefficients and physical parameters will be displayed.

The aerodynamic coefficient line numbers are:

1 – $C_{m\alpha}$	2 – $C_{m\alpha_3}$	3 – $C_{m\alpha_5}$	4 – C_{mq}
5 – $C_{mq\alpha_2}$	6 – $C_{np\alpha}$	7 – $C_{np\alpha_3}$	8 – $C_{np\alpha_5}$
9 – Cnsm	10 – $C_{m\alpha}$ mach	11 – Cx	12 – $C_{x\alpha_2}$
13 – $C_{x\alpha_4}$	14 – $C_{N\alpha}$	15 – $C_{N\alpha_3}$	16 – $C_{N\alpha_5}$
17 – $C_{Yp\alpha}$	18 – $C_{Yp\alpha_3}$	19 – Cx mach	20 – $C_{mq\alpha_4}$
21 – Cmq2-N	22 – $C_{N\alpha}$ mach	23 – Cnr2-N	24 – Clp
25 – $C_{lp\alpha_2}$	26 – Clp mach	27 – $C_{X\gamma\alpha_2}$	28 – $C_{Z\gamma\alpha_3}$
29 – $C_{Y\gamma\alpha_3}$	30 – $C_{l\gamma\alpha_2}$	31 – $C_{m\gamma\alpha_3}$	32 – $C_{n\gamma\alpha_3}$
33 – $C_{m\gamma\alpha}$	34 – $C_{n\gamma\alpha}$		

The physical parameter line numbers are:

1 – Pitch [THETA]	2 – Pitch rate
2 – Yaw [PSI]	4 – Yaw rate
5 – Travel [X]	6 – Velocity
7 – Drift [Y]	8 – Drift rate
9 – Height [Z]	10 – Vertical rate
11 – Roll [PHI]	12 – Roll rate
13 – Cma unique	14 – Inertia ratio [Ix/Iy]
15 – Cl delta	16 – $C_{Z\gamma 0}$
17 – $C_{Y\gamma 0}$	18 – $C_{m\gamma 0}$
19 – $C_{n\gamma 0}$	20 – CX0 unique
21 – Clp unique	

2. BODY FIXED LINE NUMBERS

For each shot in the analysis (up to 5), a menu of aerodynamic coefficients will be displayed. For the last shot in the fit, a menu of physical parameters is displayed. For each shot fit, menus for both aerodynamic coefficients and physical parameters will be displayed.

1 - Cmα	2 - $Cm\alpha_3$	3 - CNβ	4 - $CN\beta_3$
5 - Dmq	6 - $Cmq\alpha_2$	7 - Cnr	8 - Cnr_2
9 - $Cm\alpha_2$	10 - $CZ\alpha_2$	11 - Cnγα	12 - Cmγα
13 - Cmα-bar	14 - $Cm\alpha_3$-bar	15 - Cmq-bar	16 - $Cmq\alpha_2$-bar
17 - Cnpα-bar	18 - Cx0	19 - $Cx\alpha_2$	20 - $Cx\beta_2$
21 - Cx mach	22 - CYβ	23 - $CY\beta_3$	24 - CZα
25 - $CZ\alpha_3$	26 - CZγα	27 - CYγα	28 - CXα
29 - CYpα-bar	30 - $CX\alpha_2$-bar	31 - CNα-bar	32 - $CN\alpha_3$-bar
33 - Clp	34 - Clγα	35 - Clβ	36 - Ixy
37 - Iy/Iz	38 - Cm0	39 - CN0	40 - CY0
41 - CZ0	42 - Cl-delta	43 - Cma-unique	

The physical parameter line numbers are:

1 - Pitch [THETA]	2 - Pitch rate
2 - Yaw [PSI]	4 - Yaw rate
5 - Travel [X]	6 - Velocity
7 - Drift [Y]	8 - Drift rate
9 - Height [Z]	10 - Vertical rate
11 - Roll [PHI]	12 - Roll rate
13 - Inertial cross product [Ixy]	14 - Inertia form factor [Ix/Iy]
15 - Cm0	16 - Cn0
17 - CY0	18 - Cz0
19 - Cl delta	20 - Cmα-unique

3. FIXED PLANE INDEX NUMBERS

For fixed plane equations of motion, the index numbers in the analysis are:

1 - $C_{m\alpha}$	2 - $C_{m\alpha_3}$	3 - $C_{m\alpha_5}$	4 - C_{mq}
5 - $C_{mq\alpha_2}$	6 - $C_{np\alpha}$	7 - $C_{np\alpha_3}$	8 - $C_{np\alpha_5}$
9 - $C_{np\alpha_7}$	10 - $C_{m\alpha}$ mach	11 - $C_{m\gamma\alpha_5}$	12 - $C_{n\gamma\alpha_5}$
17 - Cx	18 - $C_{x\alpha_2}$	19 - $C_{x\alpha_4}$	20 - $C_{N\alpha}$
21 - $C_{N\alpha_3}$	22 - $C_{N\alpha_5}$	23 - $C_{Yp\alpha}$	24 - $C_{Yp\alpha_3}$
25 - Cx mach	26 - $C_{mq\alpha_4}$	27 - Cmq2-N	28 - $C_{N\alpha}$ mach
29 - Cnr2-N	32 - Clp	33 - $C_{lp\alpha_2}$	34 - Clp mach
35 - $C_{X\gamma\alpha_2}$	36 - $C_{z\gamma\alpha_3}$	37 - $C_{y\gamma\alpha_3}$	38 - $C_{l\gamma\alpha_2}$
39 - $C_{m\gamma\alpha_3}$	40 - $C_{n\gamma\alpha_3}$		

41 - Pitch [THETA]	42 - Pitch rate
43 - Yaw [PSI]	44 - Yaw rate
45 - Travel [X]	46 - Velocity
47 - Horizontal motion [Y]	48 - Horizontal rate
49 - Vertical motion [Z]	50 - Vertical rate
51 - Roll [PHI]	52 - Roll rate
53 - Cma unique	54 - Inertia ratio [Ix/Iy]
55 - Cl delta	56 - CNdA
57 - CNdB	58 - CmdA
59 - CmdB	60 - CX0 unique
61 - Clp unique	62 - Pitch rate [Q]
63 - Yaw rate [R]	64 - Velocity (missile) [U]
65 - Hor. rate (missile) [V]	66 - Vertical rate (missile) [W]
67 - Roll rate [P]	

4. BODY FIXED INDEX NUMBERS

For body fixed equations of motion, the index numbers in the analysis are:

1 - $Cm\alpha$	2 - $Cm\alpha_3$	3 - $CN\beta$	4 - $CN\beta_3$
5 - Cmq	6 - $Cmq\alpha_2$	7 - Cnr	8 - Cnr_2
9 - $Cm\alpha_2$	10 - $Cz\alpha_2$	11 - $Cm\gamma\alpha_3$	12 - $Cn\gamma\alpha_3$
13 - $Cm\alpha$-bar	14 - $Cm\alpha_3$-bar	15 - Cmq-bar	16 - $Cmq\alpha_2$-bar
17 - $Cnp\alpha$-bar	18 - Cx0	19 - $Cx\alpha_2$	20 - $Cx\beta_2$
21 - Cx mach	22 - $CY\beta$	23 - $CY\beta_3$	24 - $CZ\alpha$
25 - $CZ\alpha_3$	26 - $CZ\gamma\alpha_3$	27 - $CY\gamma\alpha_3$	28 - $CX\alpha$
29 - $CYp\alpha$-bar	30 - $CX\alpha_2$-bar	31 - $CN\alpha$-bar	32 - $CN\alpha_3$-bar
33 - Clp	34 - $Cl\gamma\alpha_2$	35 - $Cl\beta$	

41 - Pitch [THETA]	42 - Pitch rate
43 - Yaw [PSI]	44 - Yaw rate
45 - Travel [X]	46 - Velocity
47 - Horizontal motion [Y]	48 - Horizontal rate
49 - Vertical motion [Z]	50 - Vertical rate
51 - Roll [PHI]	52 - Roll rate
53 - Inertial cross product [Ixy]	54 - Axial Inertia [Ix]
55 - CM0-trim	56 - CN0-trim
57 - CY0-trim	58 - CZ0-trim
59 - Cl-delta	60 - $Cm\alpha$-bar
61 - Not used	62 - Pitch rate [Q]
63 - Yaw rate [R]	64 - Velocity (missile) [U]
65 - Drift rate (missile) [V]	66 - Drop rate (missile) [W]
67 - Roll rate [P]	